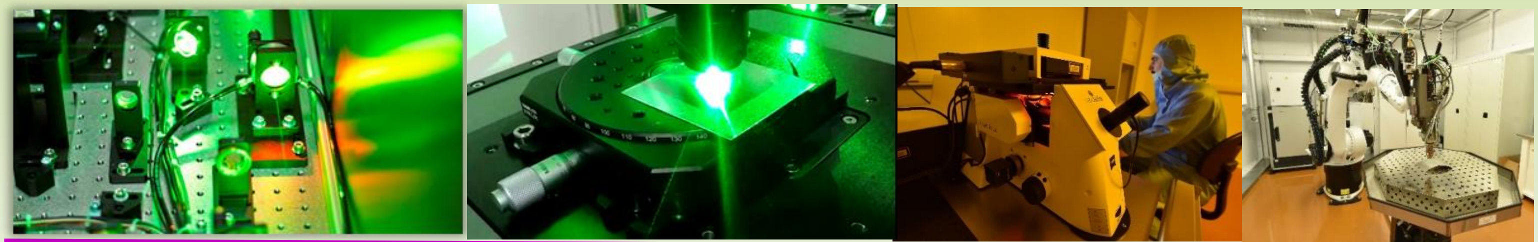
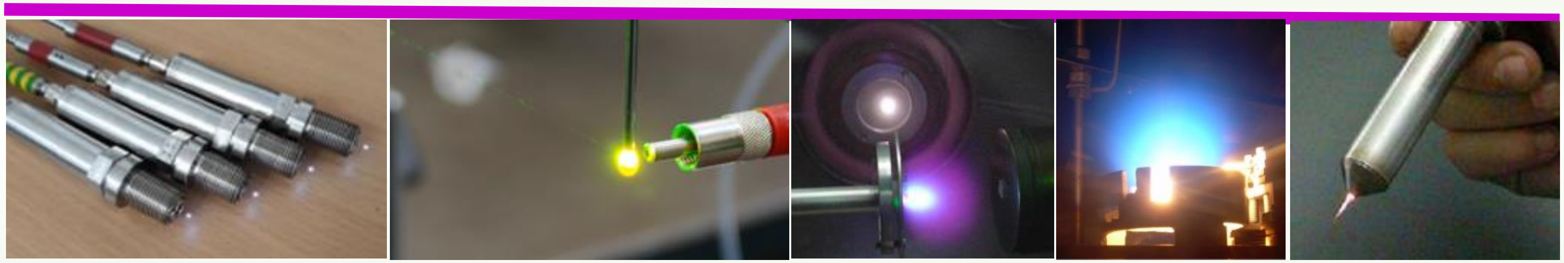
Emerging technologies with intense electromagnetic fields and plasma



National Institute for Laser, Plasma and Radiation Physics



for energy, life sciences, environment, communications and security

http://www.inflpr.ro

http://tomography.inflpr.ro

Ion TISEANU
ion.tiseanu@inflpr.ro

Motivation

X-ray tomography is an imaging technique for non-invasive volumetric characterization of materials and processes

It can be used in optimization of processes of waste valorization as:

- recycling & resource recovery (ex. rare earths, tungsten);
- pelletization of coal ash or fly ash resulted from solid waste incinerators;
- production of composites from waste recycled armor materials and natural matrix (ex. volcanic ash, mortar);
- characterization of waste recycled glass/textile fibers to be used in composites;
- production of ultra-light composites used as building materials;
- characterization of wood-plastic composites;
- advanced characterization and modeling of porous materials (ex. charcoal pellets) …

It could provide a unique access channel for a fully non-invasive inspection and quantitative analysis of some hazardous waste.

http://tomography.inflpr.ro

Applications of X-ray microtomography in microstructural analysis of materials resulting from waste processing

Outline

- **Tomography equipment**
- **Porosity analysis & fluid transport in porous media**
- **Passive treatment to remediate contaminated water from acid mine drainage**
- **Tomography analysis of fly ash pelletization process**
- **Volumetric analysis of composite materials based on waste of metal or wood processing**
- **Geological CO2 storage**

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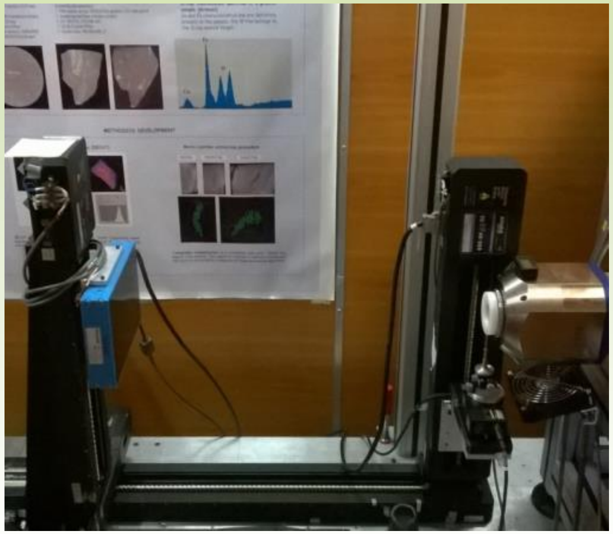
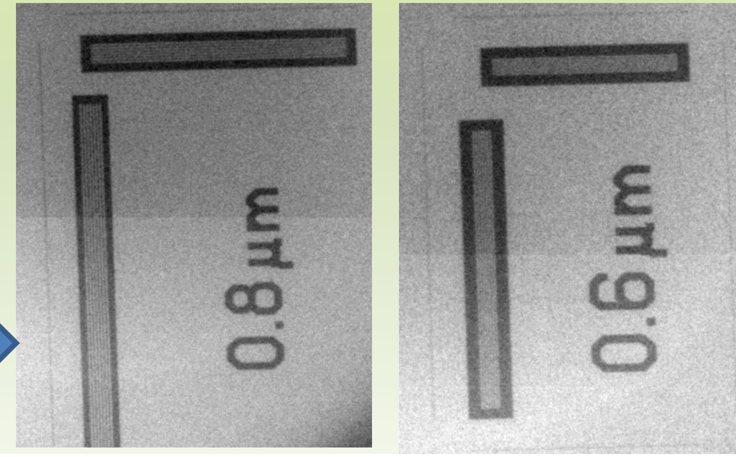
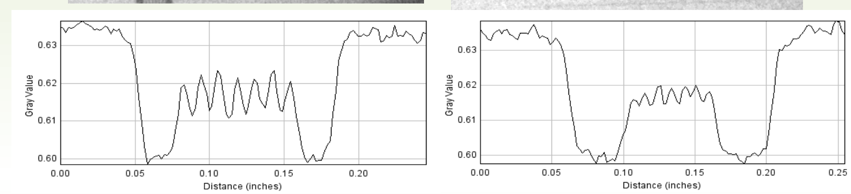
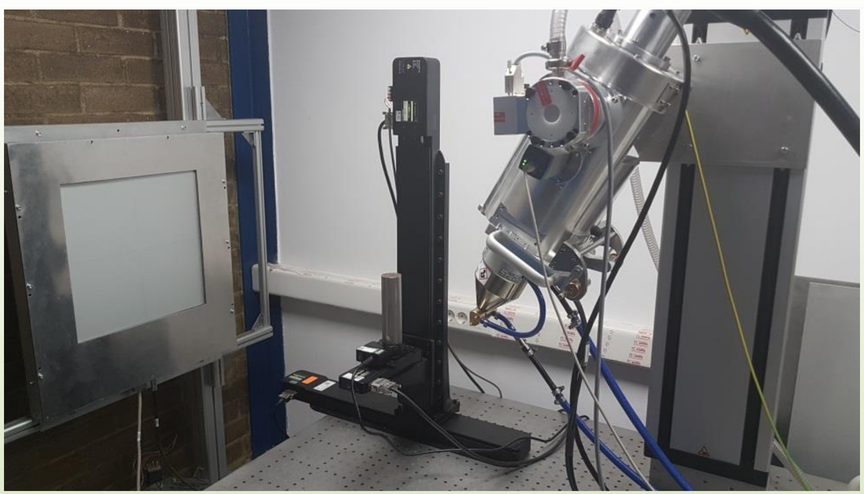
Tomography Equipment

submicron resolution









High penetration power microfocus @ 320 kV

Technical data of various XCTs

Type		X-ray source	Voxel size
Medical XCT-systems	Med-XCT	140 kV rotating anode tube	$>(0.3\ mm)^3$
Cone beam XCT: Rayscan 250E or v|tome|x s 240	µXCT	225 kV µ-focus tube	$>(2\ \mu m)^3$
Cone beam XCT: nanotom 180	Sub-µXCT	180 kV nanofocus tube	$>(0.4\ \mu m)^3$
INFLPR NanoCT	Sub-µXCT	**225 kV nanofocus tube**	$>(0.5\ \mu m)^3$
INFLPR XCT	µXCT	**225 kV µ-focus tube** **320 kV µ-focus tube**	$>(2\ \mu m)^3$ $>(10\ \mu m)^3$
Synchrotron XCT: Grenoble, ESRF-ID19	sXCT	7–60 keV	$>(0.2\ \mu m)^3$

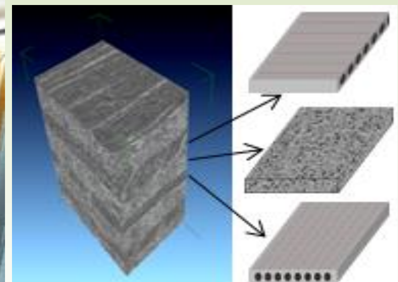
NDT E Int. 2010 Oct; 43(7-3): 599–605.

X-ray microtomography

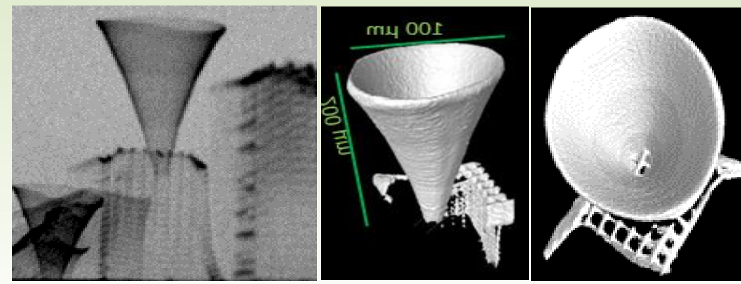
Equipment for X-Ray microtomography analysis and compositional mapping

Four versatile tomography units designed and constructed in INFLPR with energies from 50 to 320 keV and sub-micron feature recognition.
Wide variety of applications with samples sizes from 5 m down to 100 µm

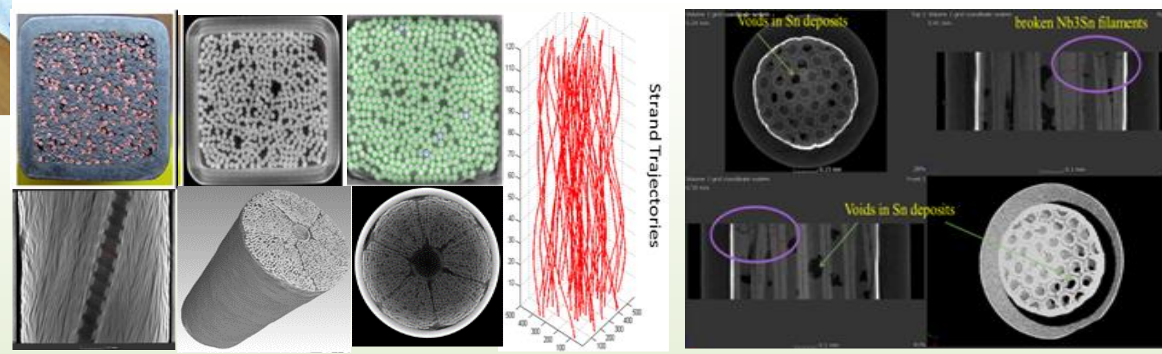
Carbon Fiber Composite



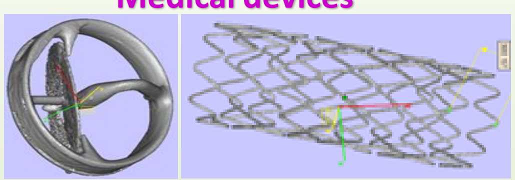
3D targets for high power laser interaction



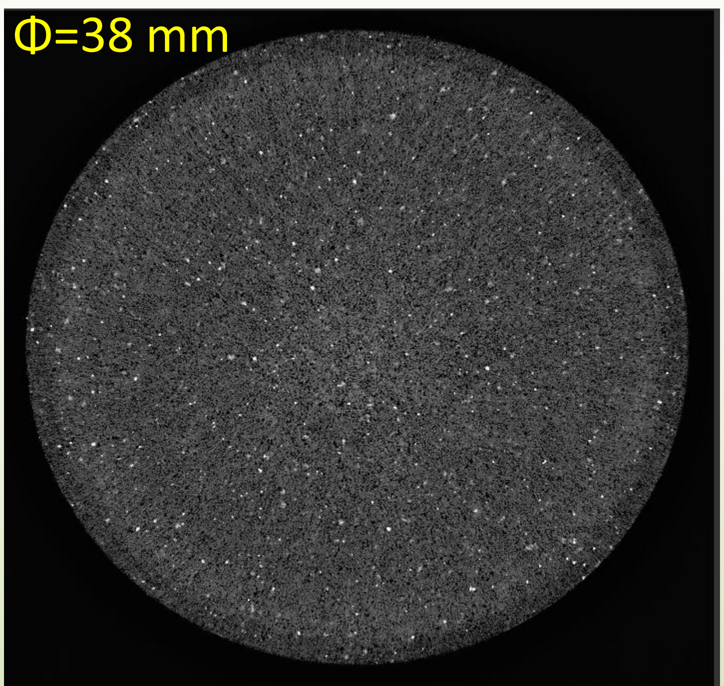
X-Ray Microtomography analysis of superconductor strand & cables

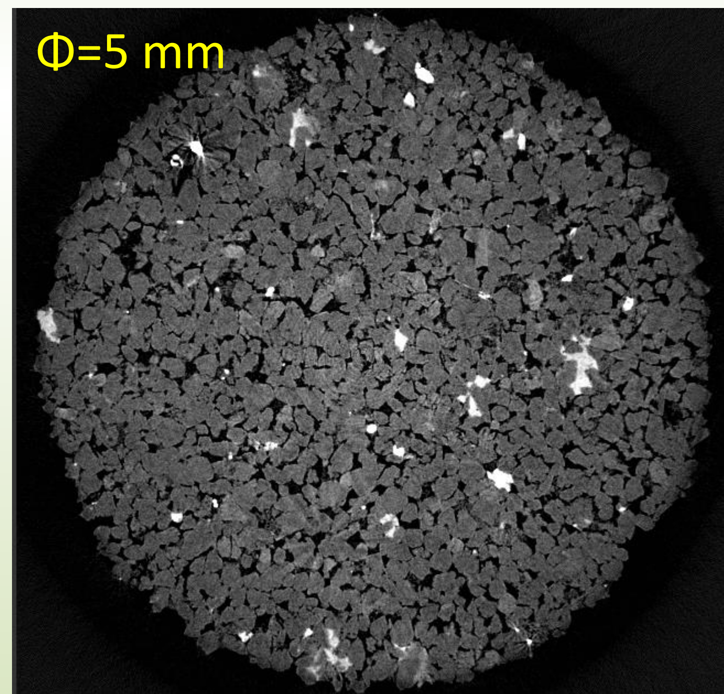


Medical devices

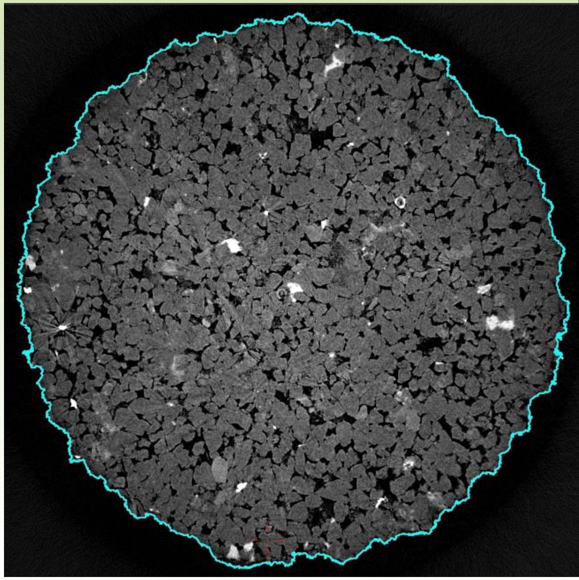


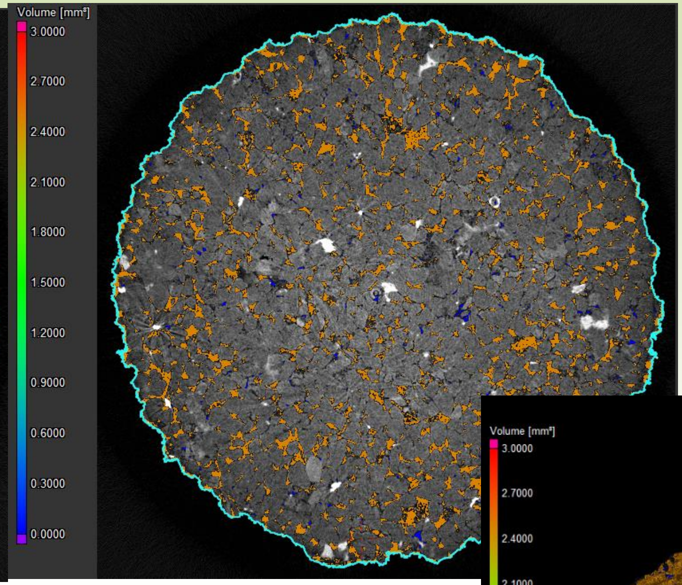
Berea sandstone multi-resolution analysis



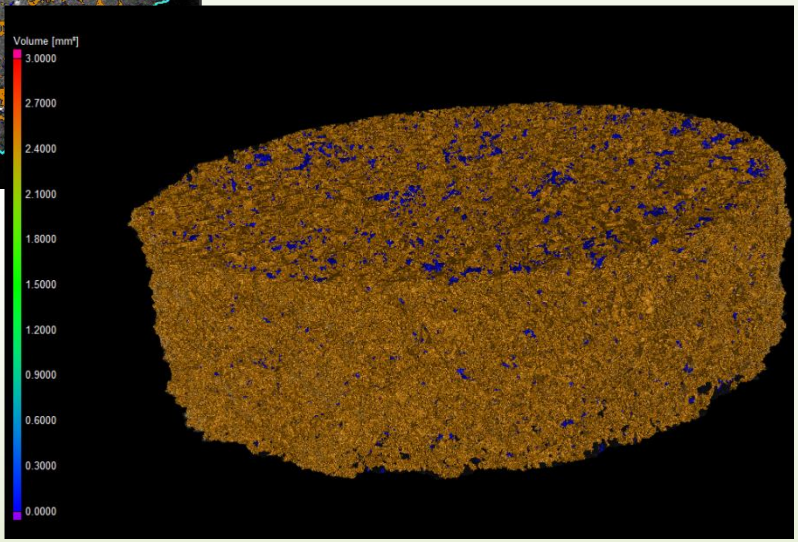


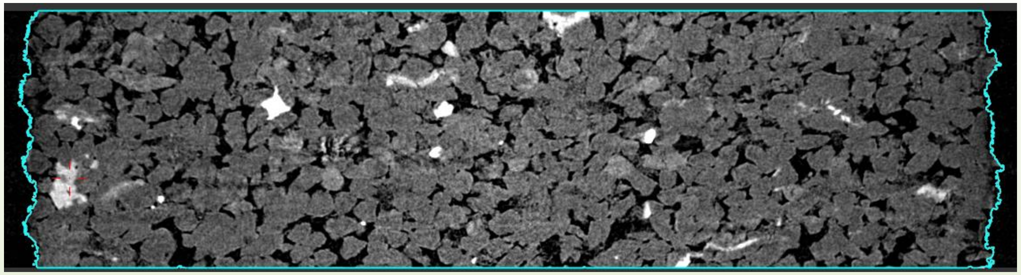
Berea sandstone Φ= 5 mm - pore analysis

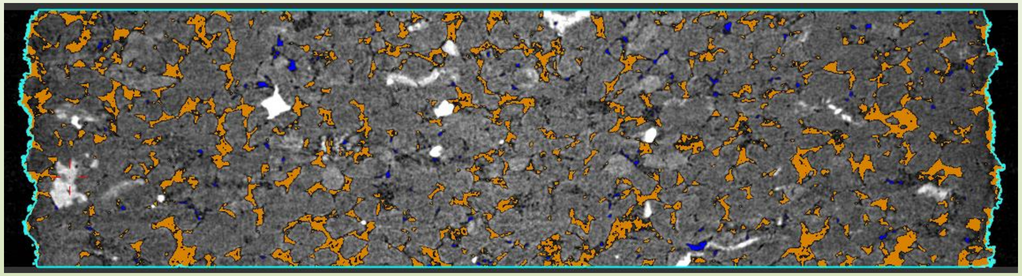




Porosity classification
by volume, area, shape,
connectivity etc.



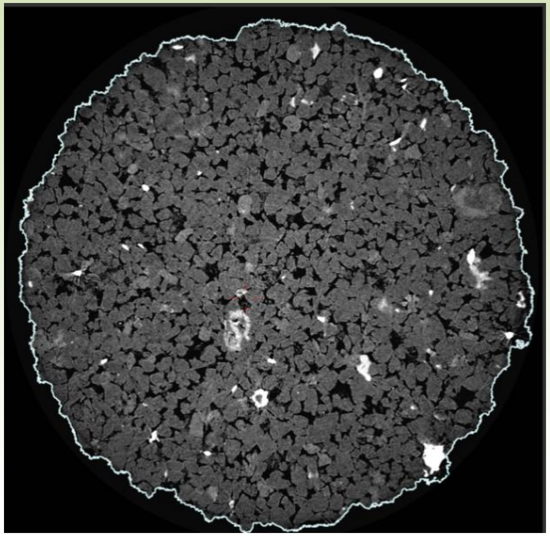


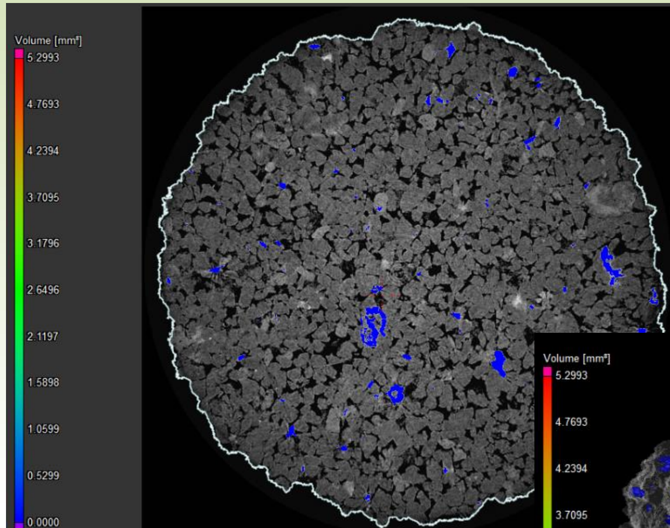


Material

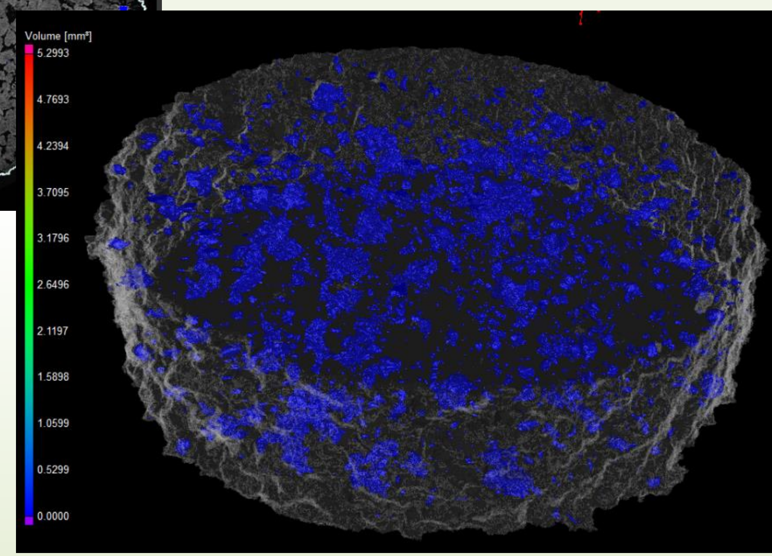
Material volume [mm³]	20.4175
Defect volume [mm³]	2.5514
Defect volume ratio [%]	11.11

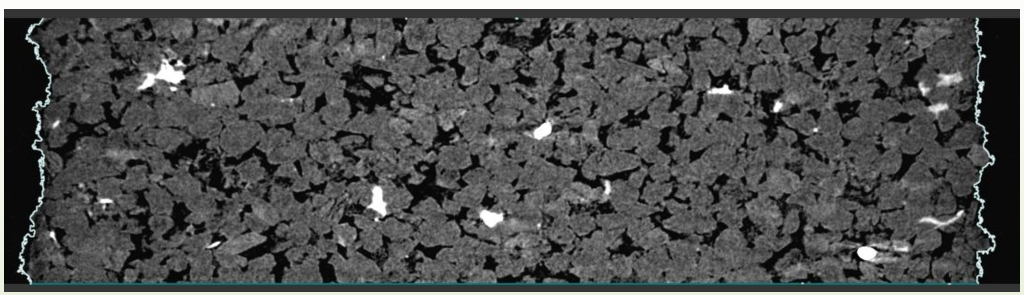
Berea sandstone Φ= 5 mm – inclusions analysis

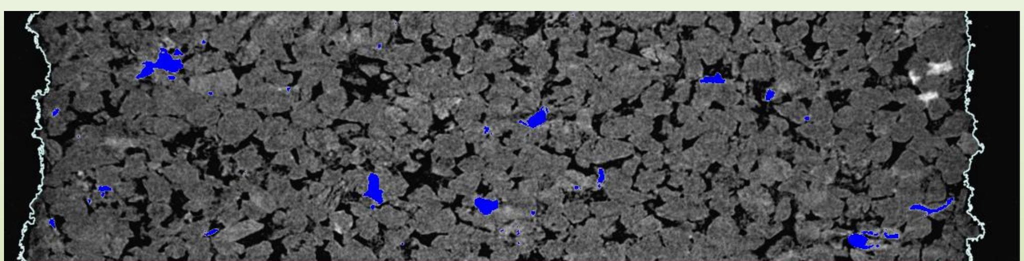




Inclusion analysis:
volume, area, shape,
density, composition etc.



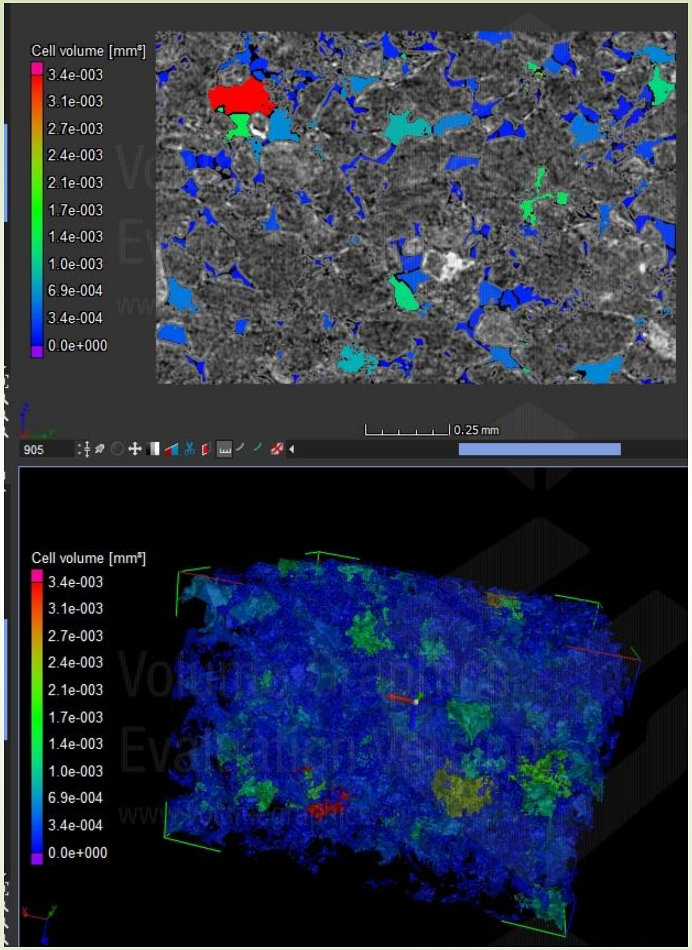




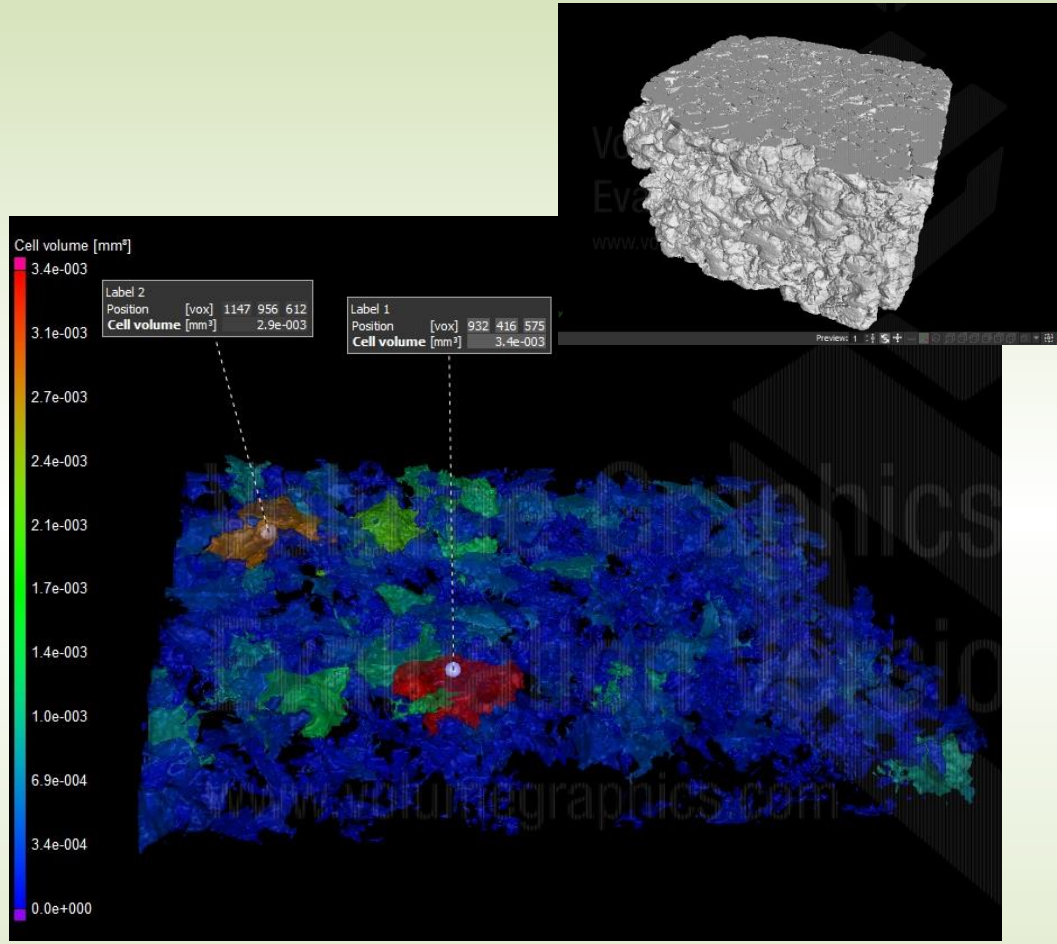
Material

Material volume [mm³]	22.7257
Defect volume [mm³]	0.2432
Defect volume ratio [%]	1.06

Berea sandstone 2 mm - submicron pore analysis



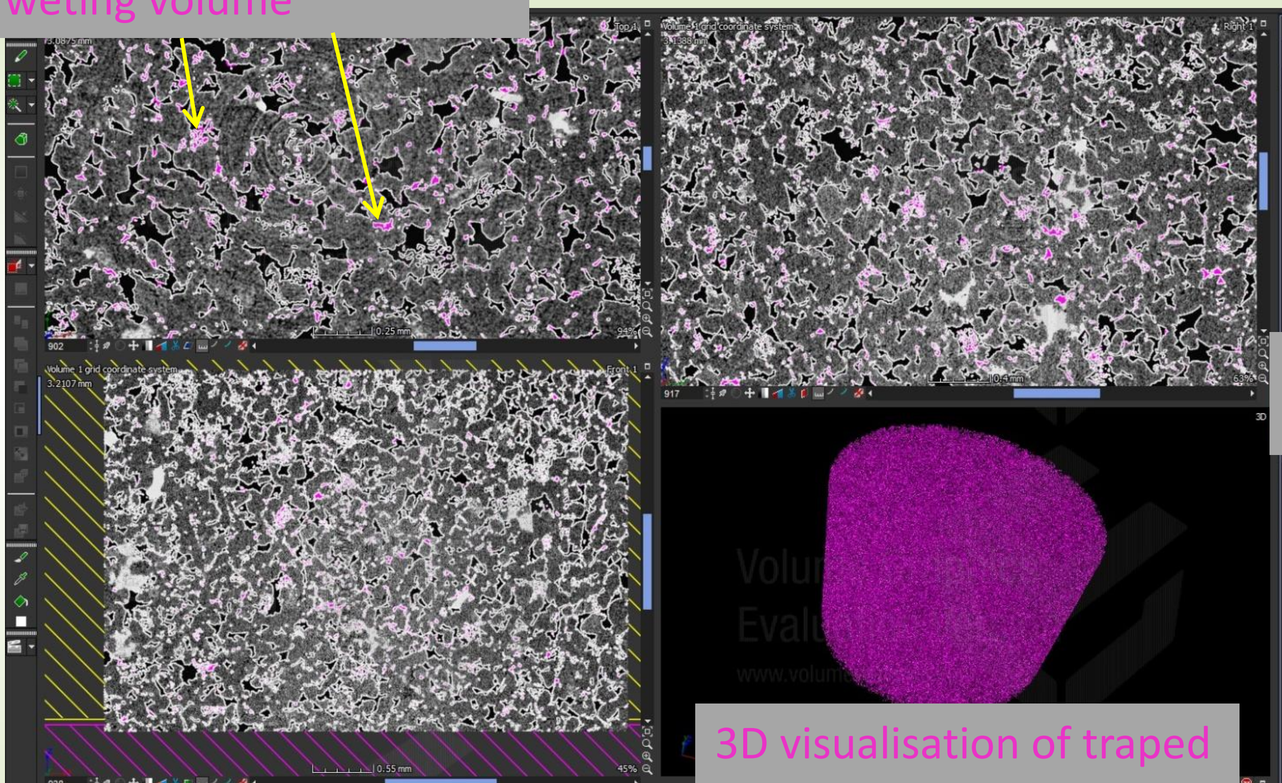
3D representation of all pores from reconstructed volume



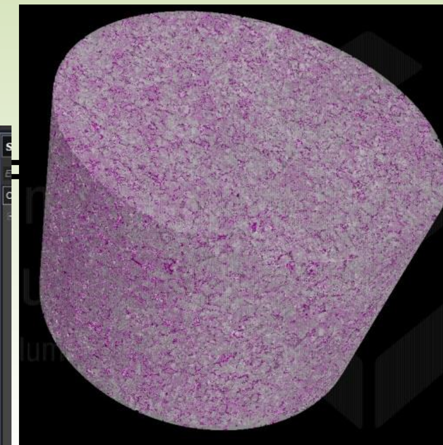
ROI – magnified inner pores in 3D

Capilary presure simulation Φ=6 mm – wetting phase

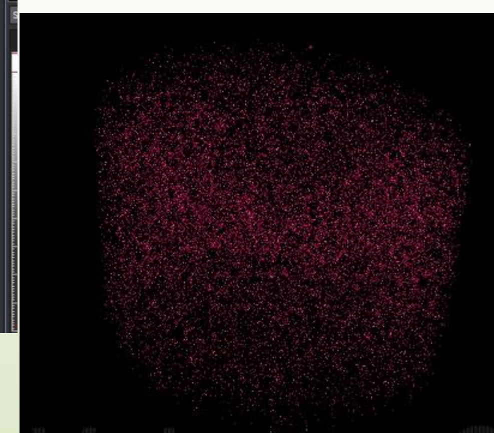
2D visualisation of traped weting volume



3D visualisation of traped wetting phase

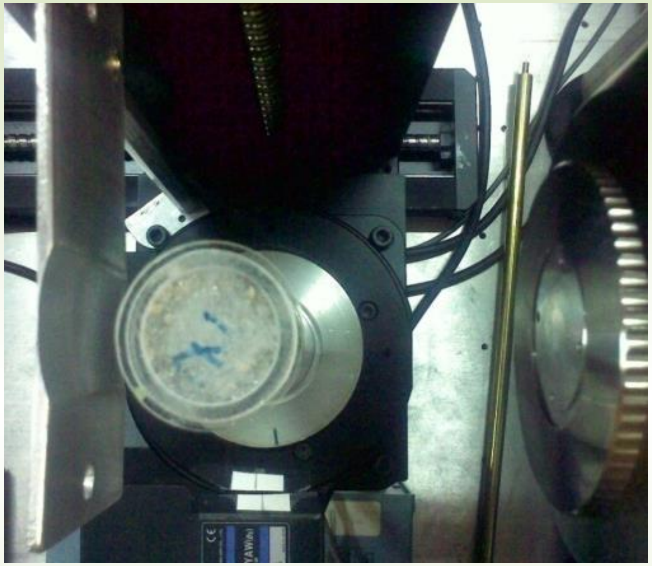


3D visualisation of weting phase traped in all volume

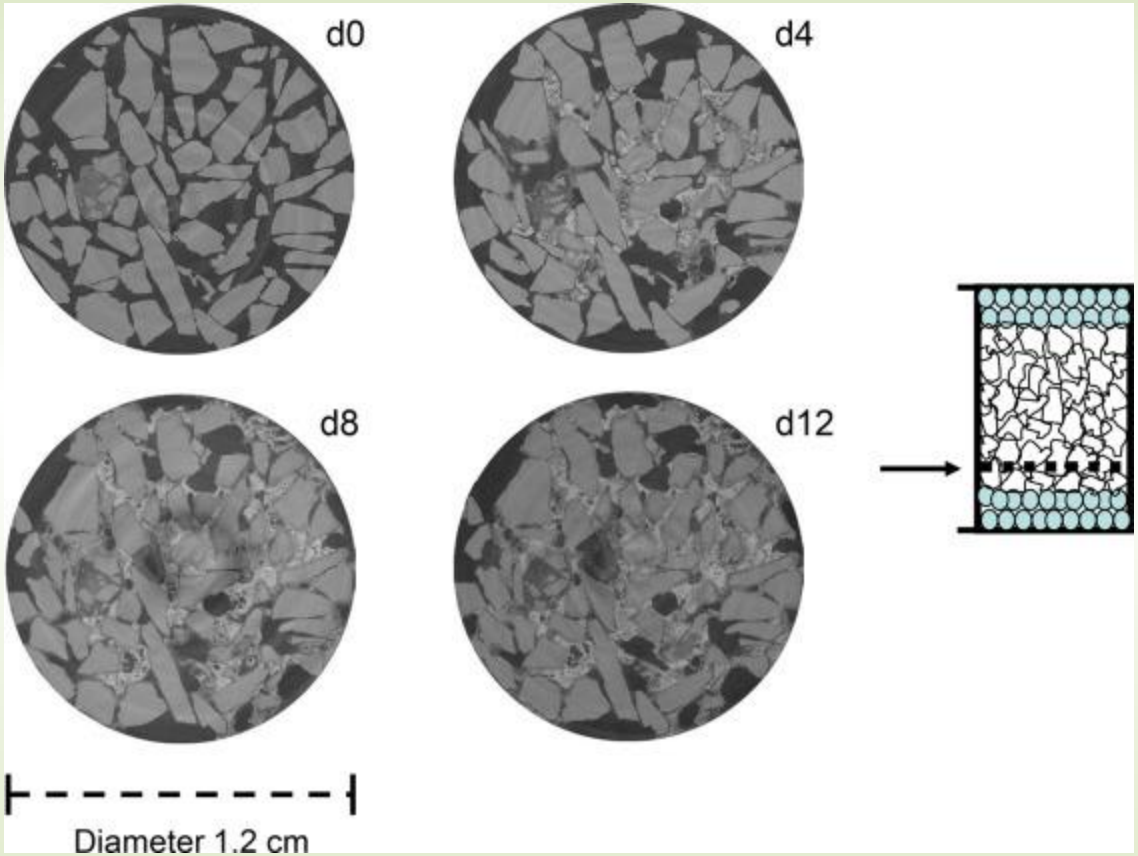


3D visualisation of isolated pore space

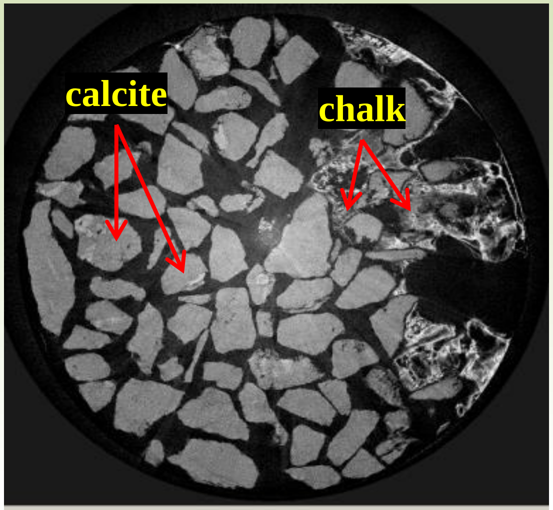
Passive treatment systems designed to remediate contaminated water from acid mine drainage



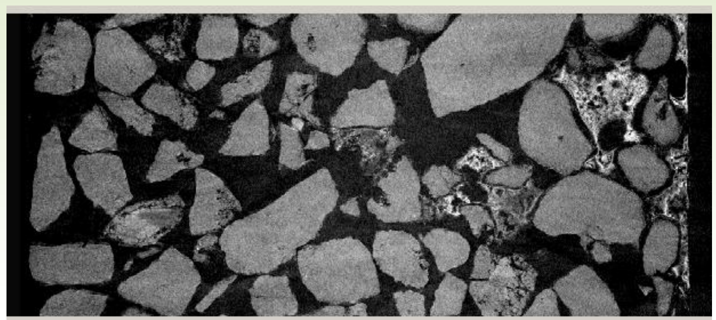
Four CT images of the same section: before **drainage**; after 4, 8 and 12 days (passivation at ≈300 h).

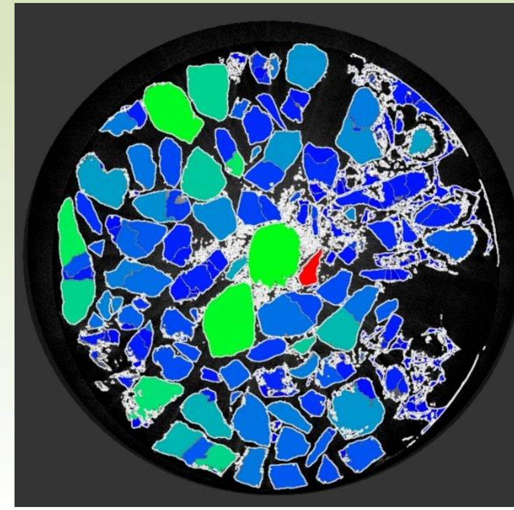


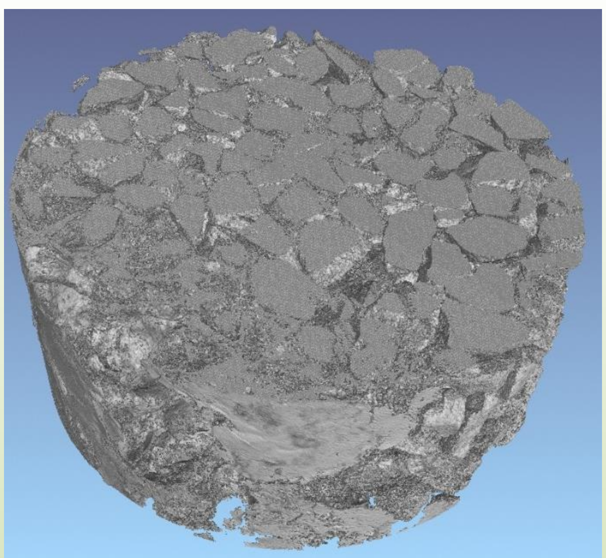
Passive treatment systems designed to remediate contaminated water from acid mine drainage

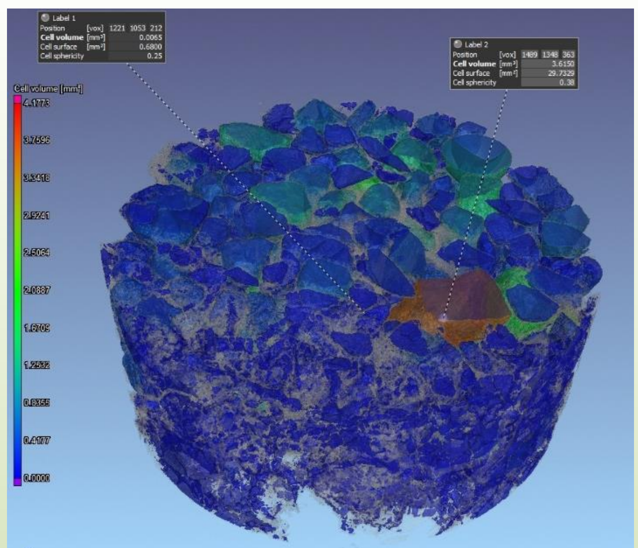


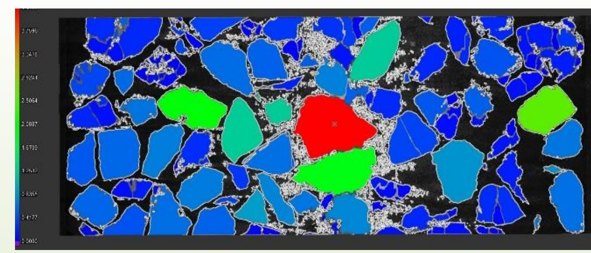
Rocks and mineral grain filter (such as calcite, aragonite or dolomite) with size grain between 1-2 mm

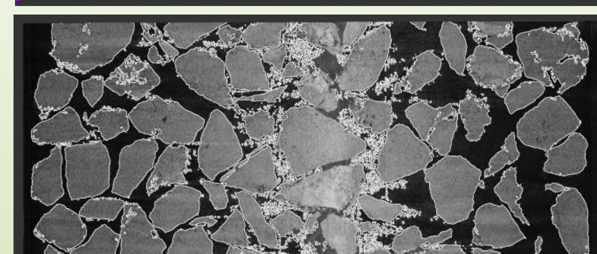






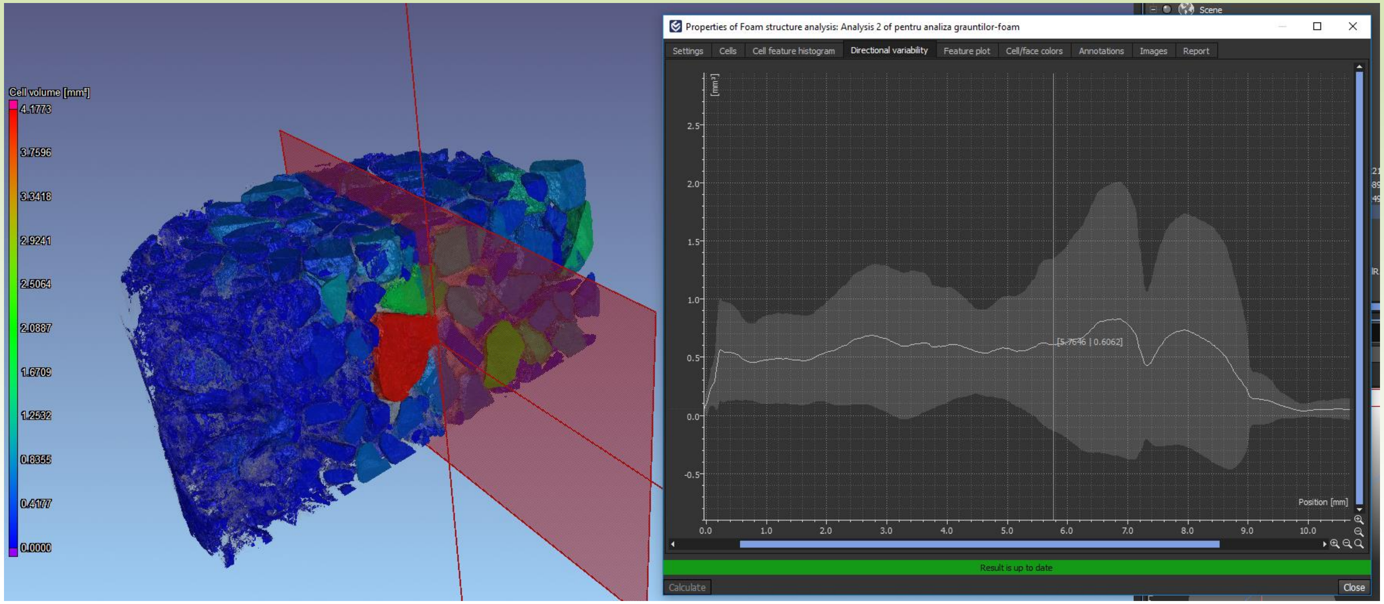




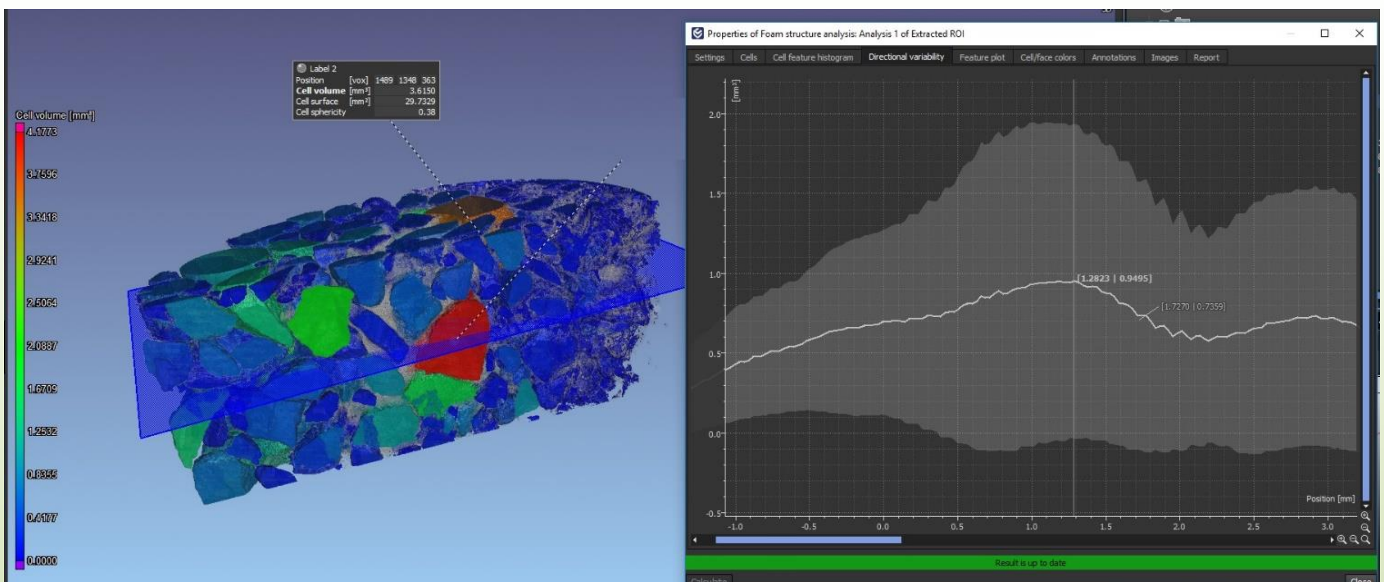


Passive treatment systems designed to remediate contaminated water from acid mine drainage

Directional variability

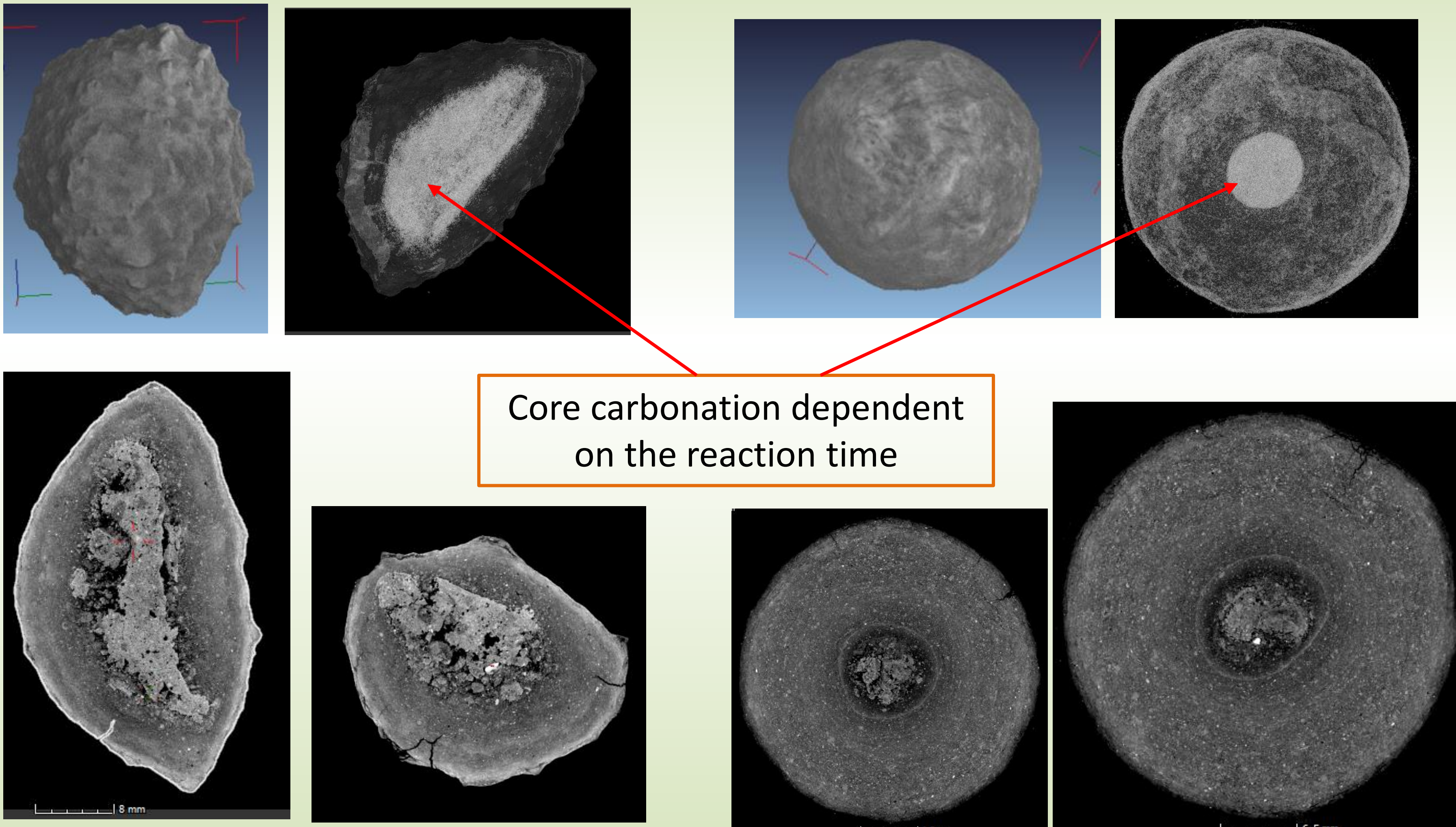


Grain orientation on right view sections



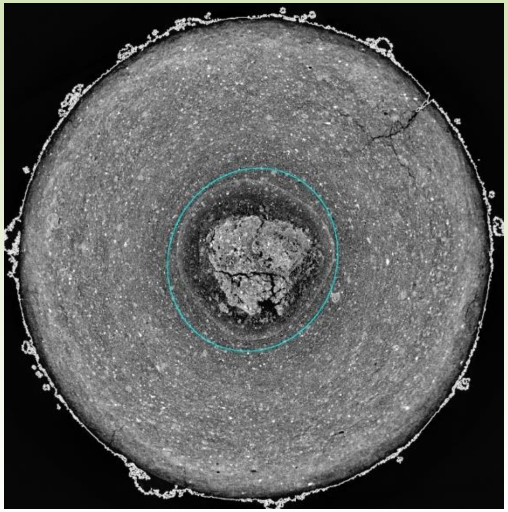
Grain orientation on top view sections

Tomography analysis of fly ash pelletization process

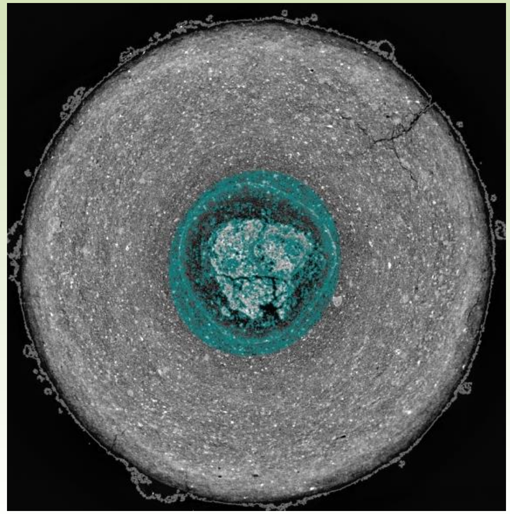


Tomography analysis of fly ash palletization process

Core analysis

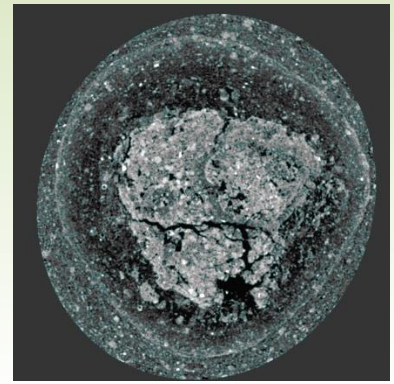


ROI selection

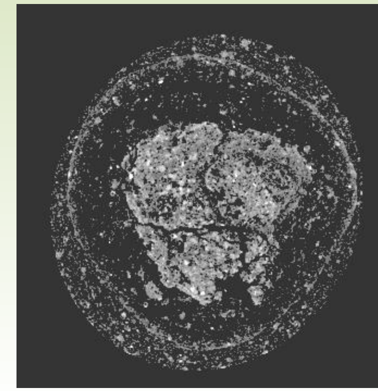


Surface determination on selected ROI

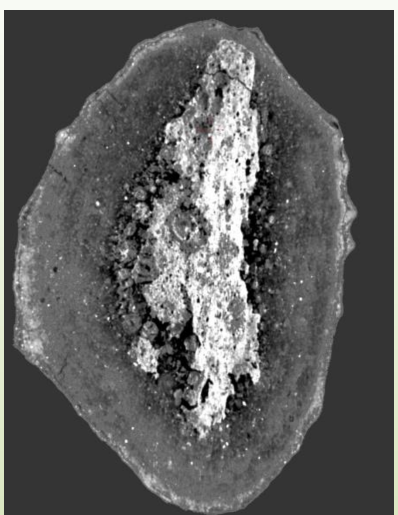
Extracted core volume: 16.04%



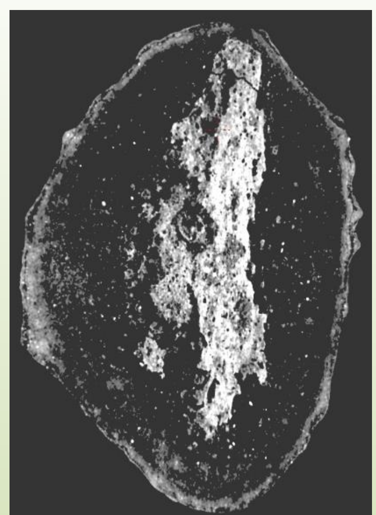
Extracted ROI with surface determination



Extracted core

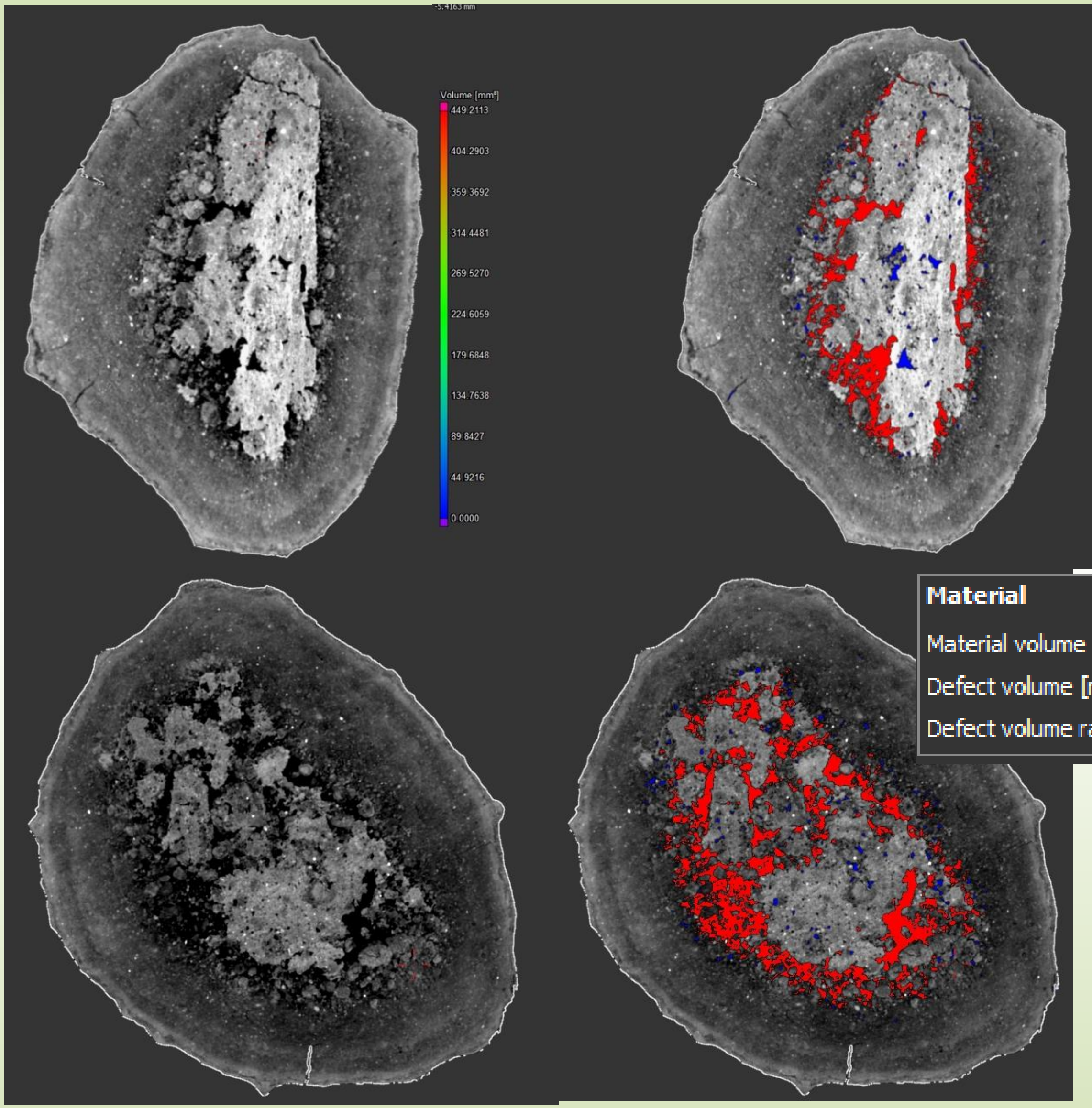


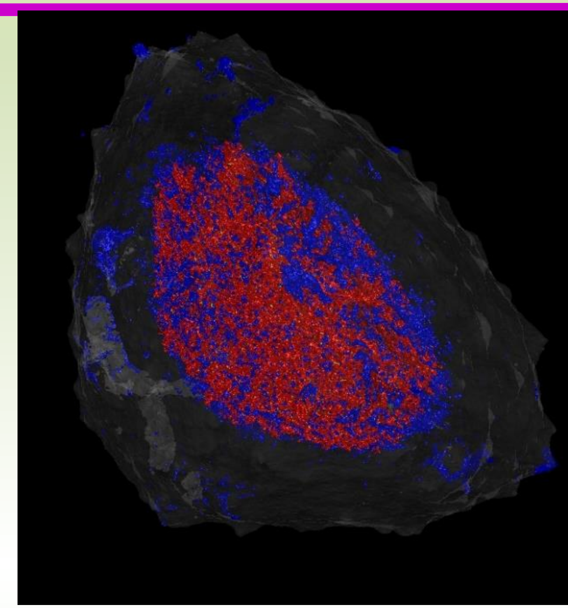
Extracted core



Extracted core volume: 32.92%

Tomography analysis of fly ash pelletization process
Porosity analysis



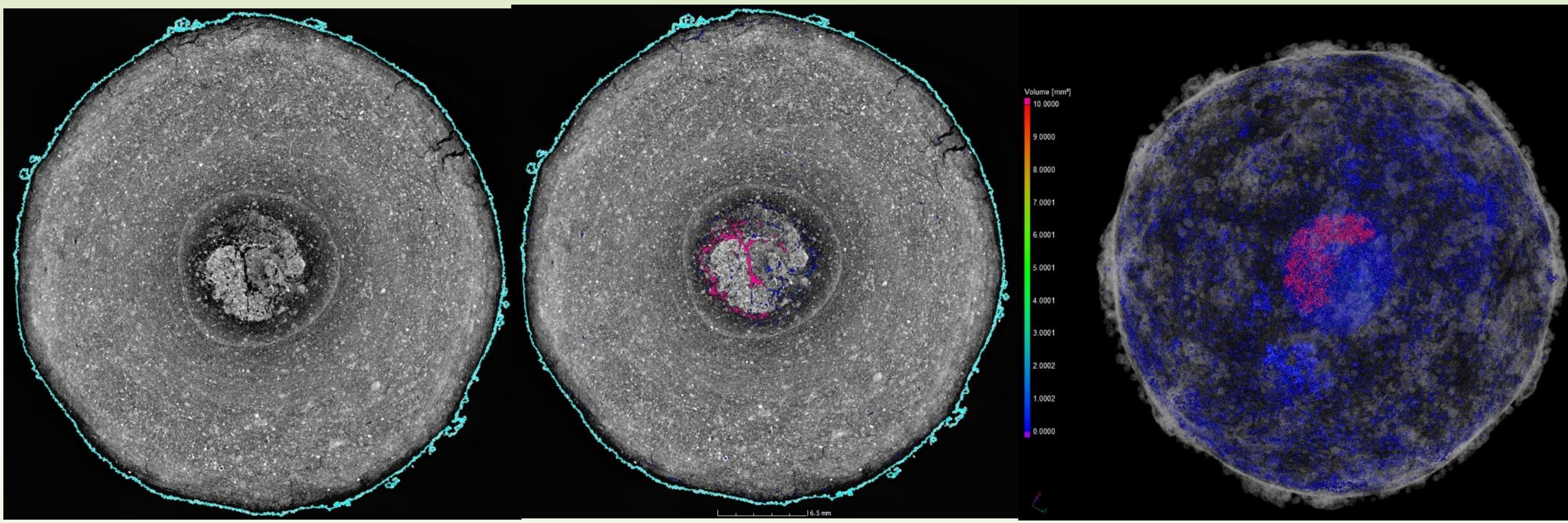


Material

Material volume [mm³]	16182.7490
Defect volume [mm³]	419.9989
Defect volume ratio [%]	2.53

Tomography analysis of fly ash palletization process

Porosity analysis

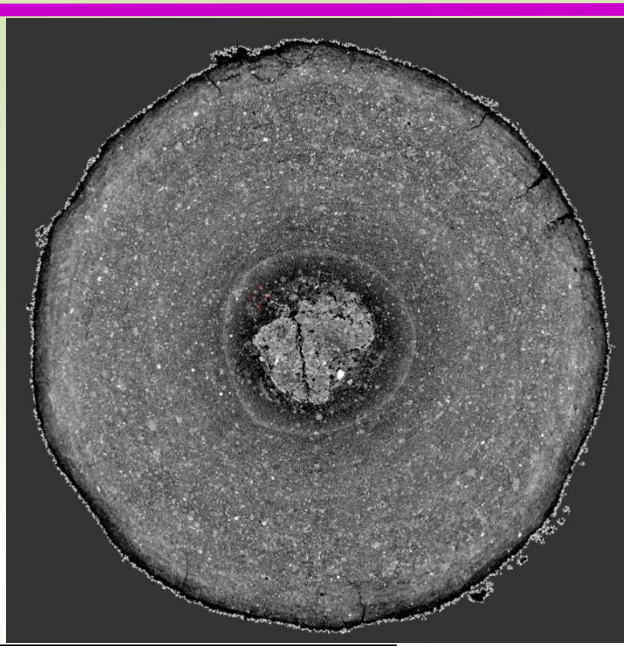


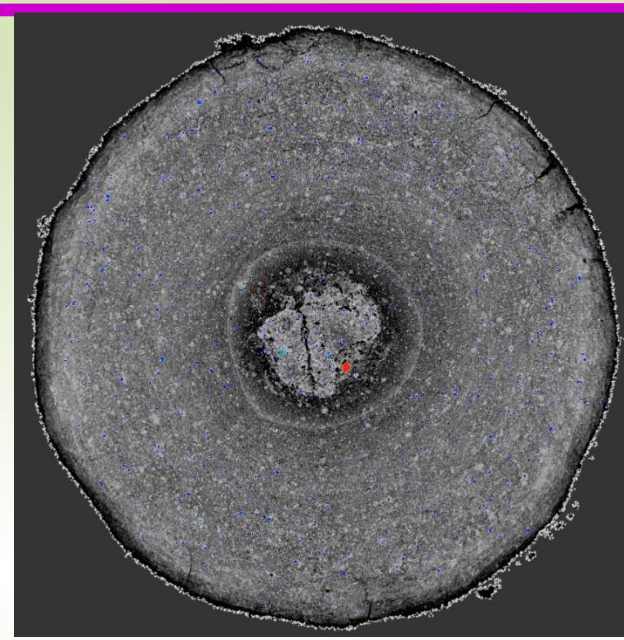
Material

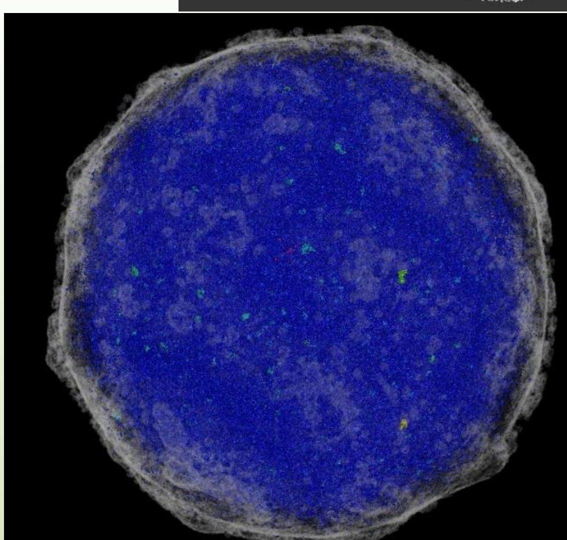
Material volume [mm³]	22409.8594
Defect volume [mm³]	44.6834
Defect volume ratio [%]	0.20

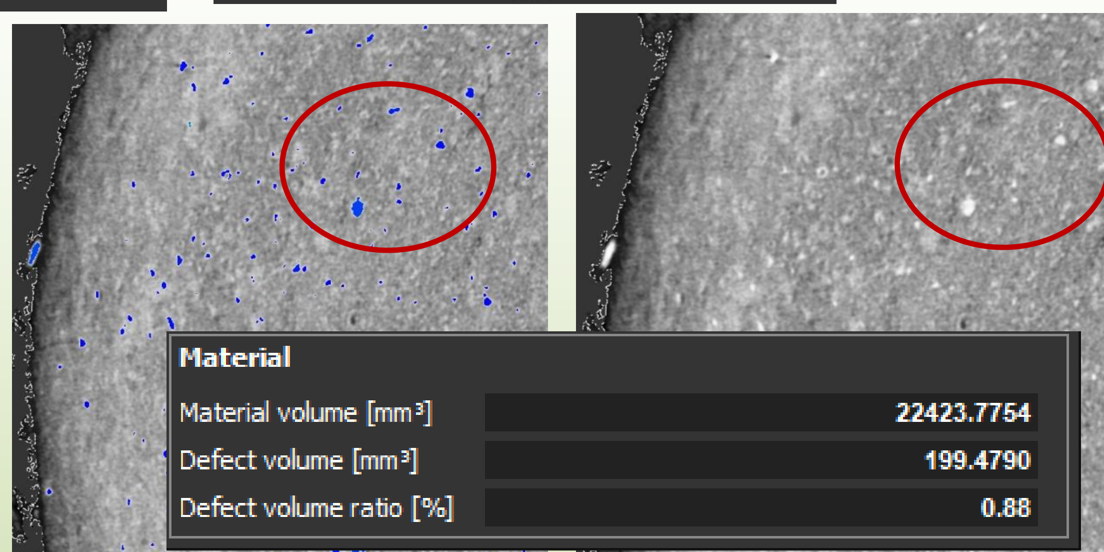
Tomography analysis of fly ash palletization process

Inclusions analysis

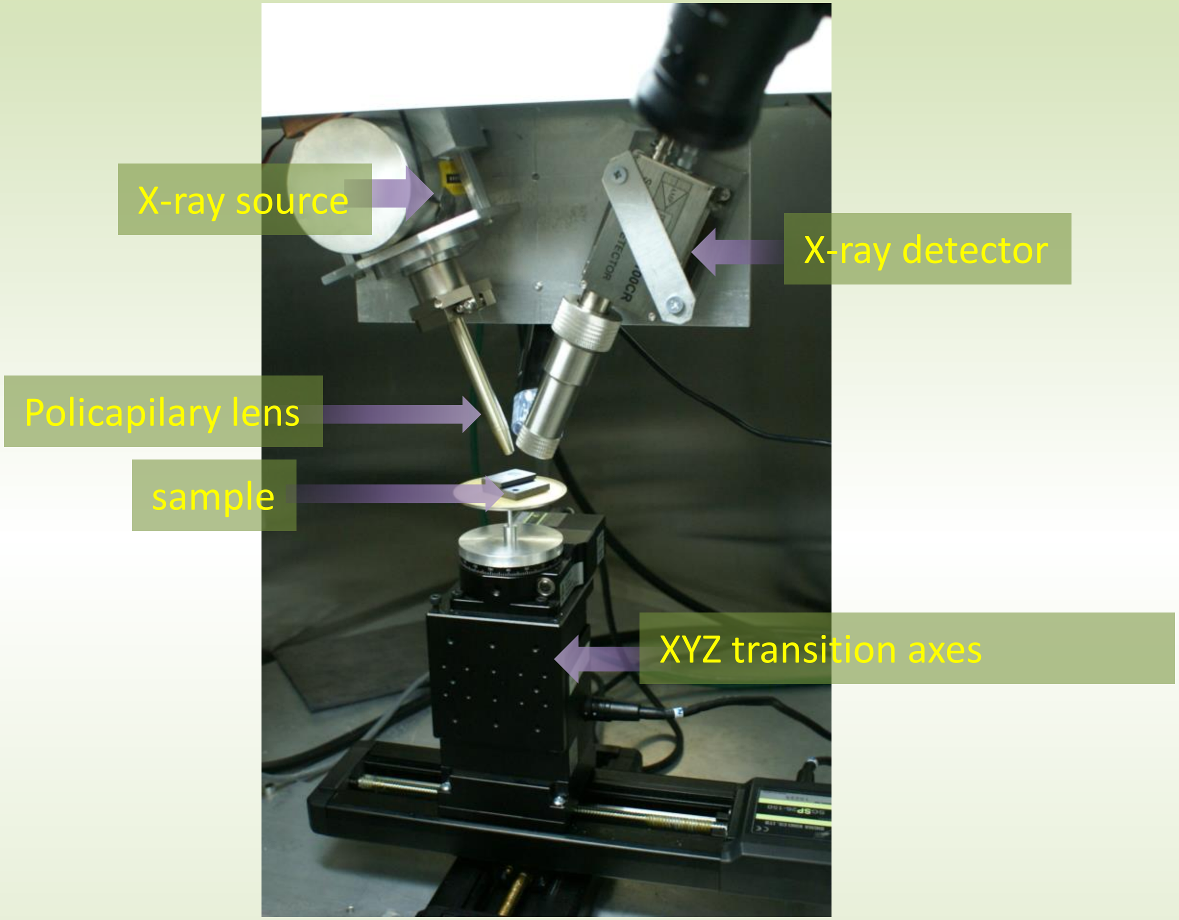






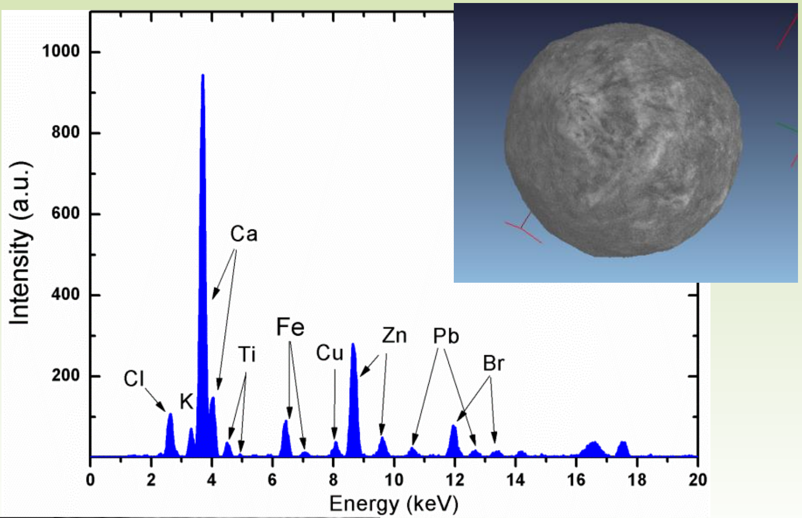


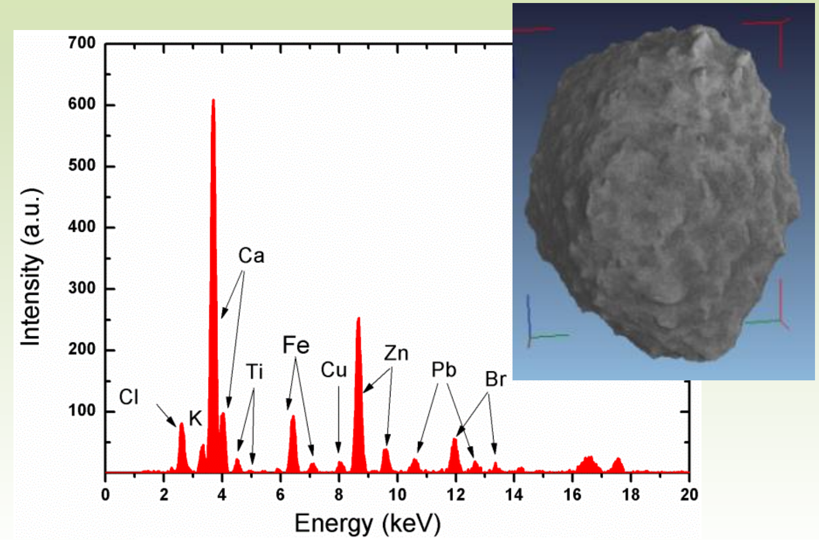
Composition mapping by microbeam X-ray fluorescence microXRF



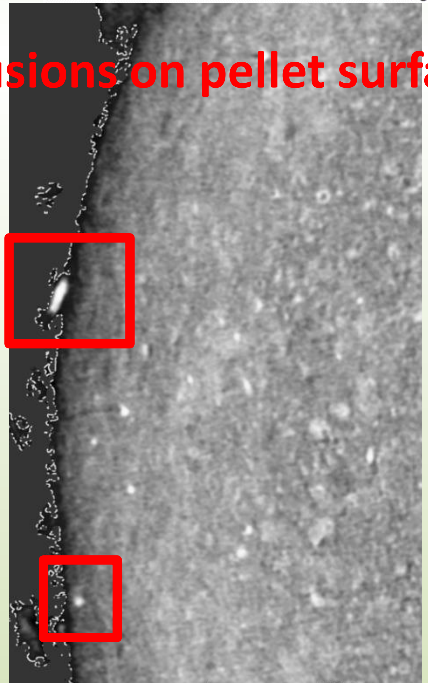
Standardless procedure for elemental composition

Elemental composition of fly ash pellets by microXRF





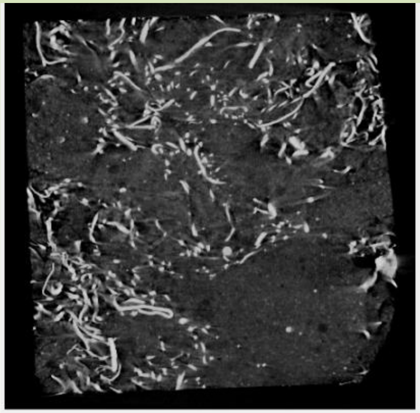
Inclusions on pellet surface

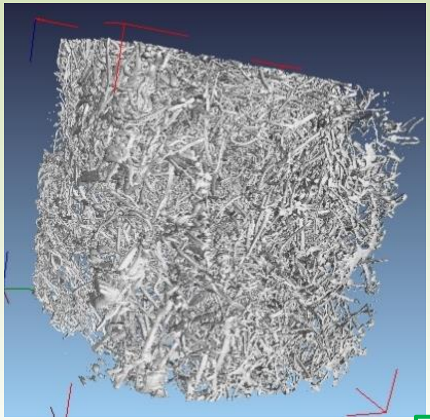


Element	Concentratie (wt%)
Fe	1,92
Cl	8,54
K	5,57
Ca	76,11
Cu	0,45
Zn	3,23
Pb	0,65
Ti	2,74
Br	0,79

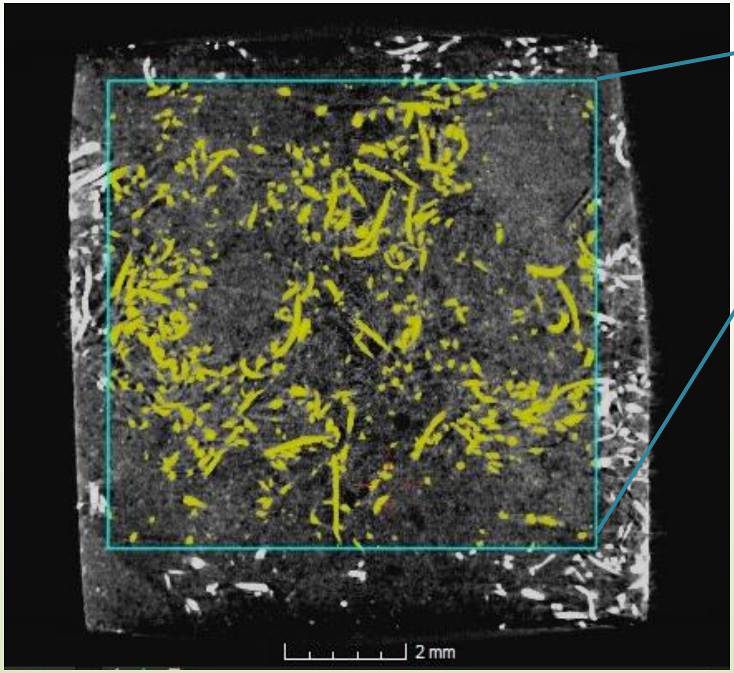
Element	Concentratie (wt%)
Fe	2,94
Cl	9,16
K	6,18
Ca	73,25
Cu	0,34
Zn	4
Pb	1,03
Ti	2,26
Br	0,83

Volumetric analysis of waste based composite materials volcanic ash & metallic insertions





Composite material made by vulcanic ash (matrix) and metallic swarf (insertions)



Selected ROI

Values (grid coordinate system)	
Min.:	34356.00
Max.:	50445.00
Mean:	36666.64
Deviation:	2219.04
Volume [mm³]	62.77
Number of voxels:	136268705
Between cursors [%]:	12.17

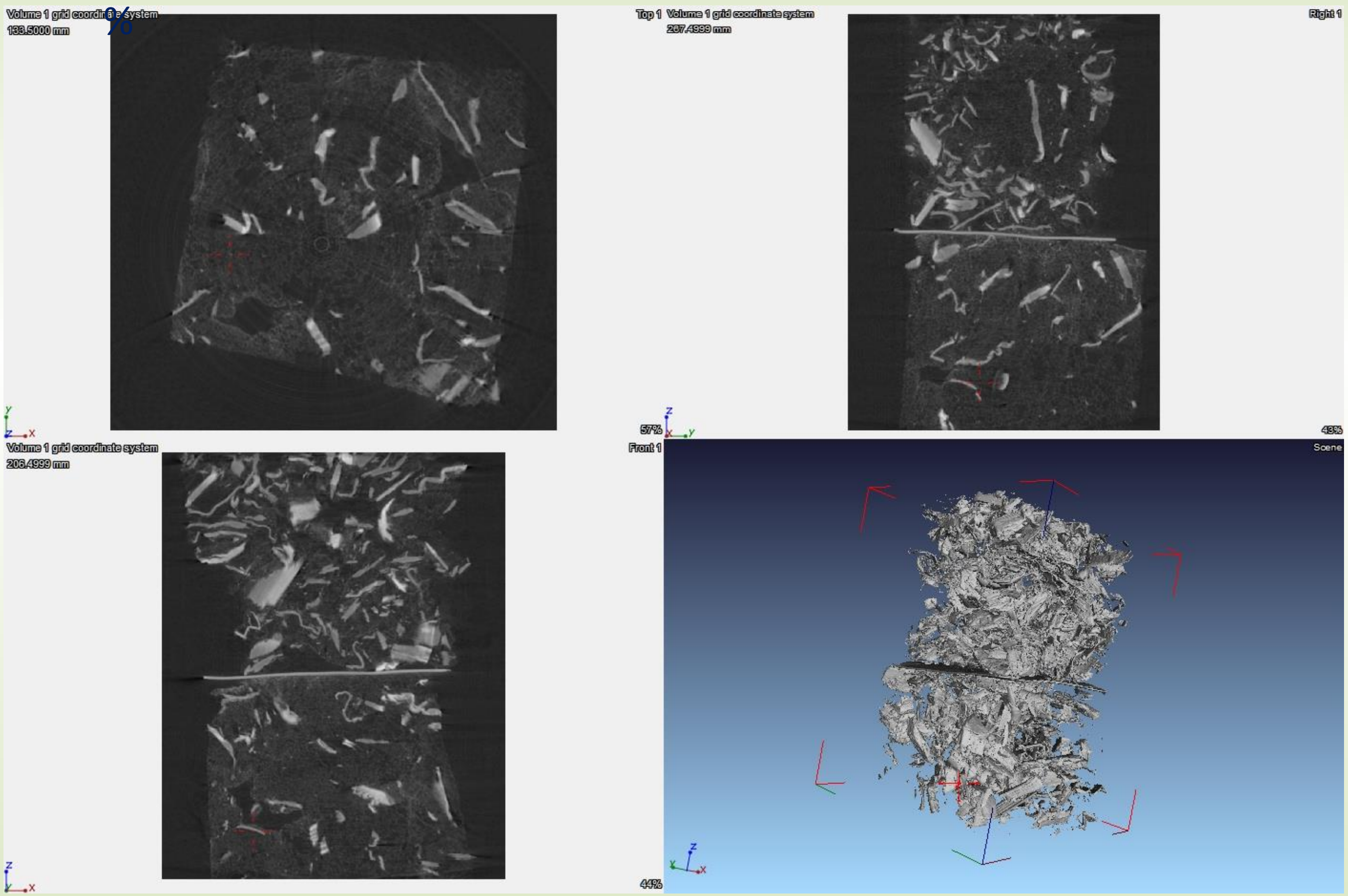
Total volume of metalic insertions from selected ROI

Volumetric analysis of waste based composite material foam matrix & wood fibers

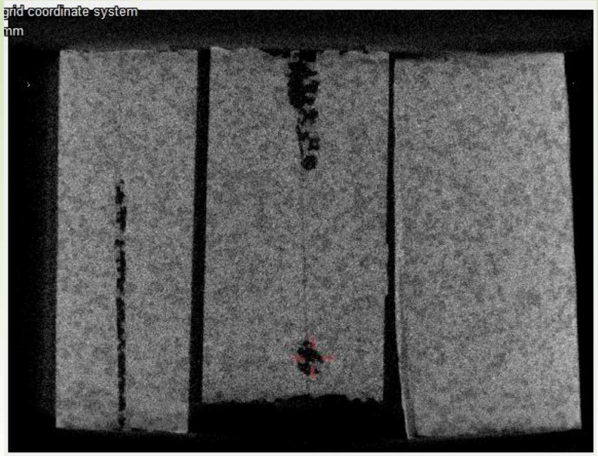
Space resolution 30 µm/voxel

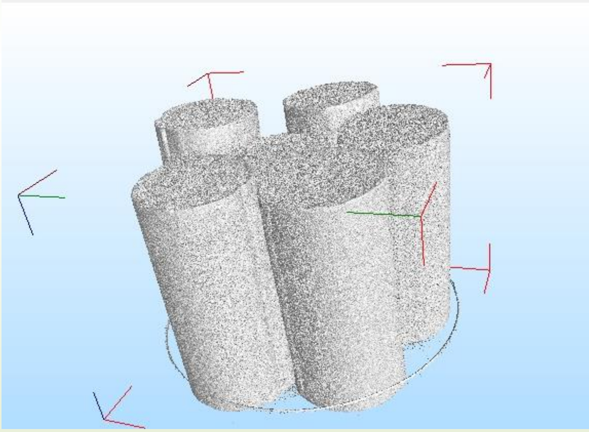
Top: wood to matrix ~ 8.25%

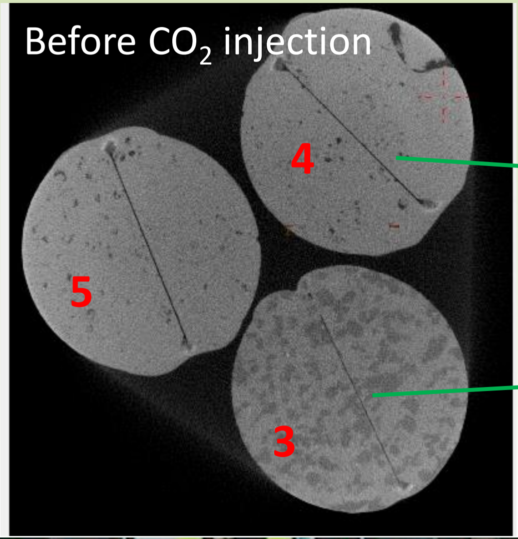
Bottom: wood to matrix ~ 7.0 %

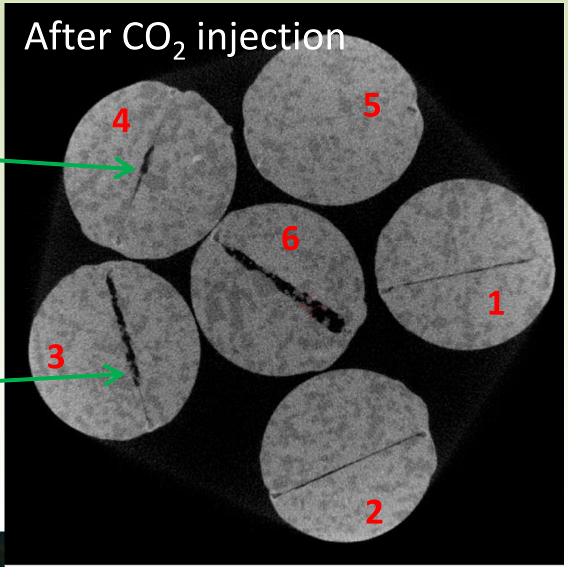


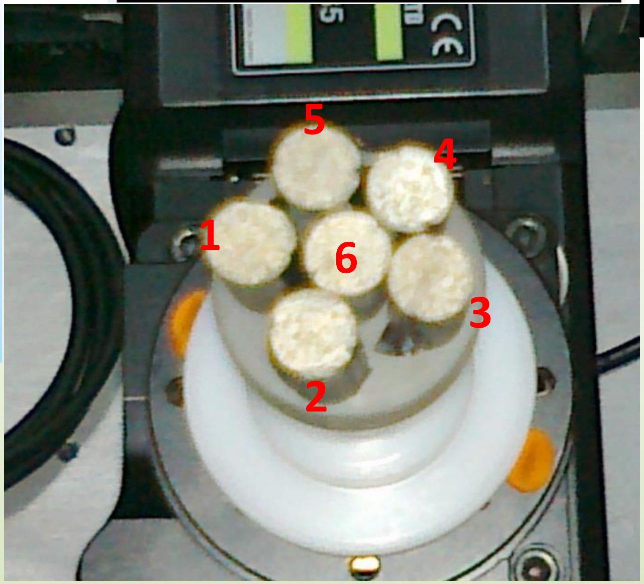
Geological CO_2 storage











The reservoir rocks are composed of limestone (calcite) and sandstone (66 wt.% calcite, 28 wt.% quartz and 6 wt.% microcline)

CO_2-rich acid brine will likely promote the dissolution of carbonate minerals (calcite) and aluminosilicates (microcline).

These coupled dissolution and precipitation reactions may induce changes in porosity and pore structure of the repository rocks