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CHEMICAL DEGRADATION OF A NUMERICALLY GENERATED MATERIAL - APPLICATION FOR FONTAINEBLEAU SANDSTONE

K. Wojtacki^{1,*}, L. Daridon^{1,2}, Y. Monerie^{1,2}

¹ Laboratoire de Mécanique et Génie Civil (LMGC), CNRS UMR 5508, Montpellier, France

² Laboratoire de Micromécanique et Intégrité des Structures (MIST), UM, CNRS, IRSN, France



Highlights

1. Simple and efficient method that allows to obtain morphologically equivalent realisations of Fontainebleau sandstone
2. New method allowing to impose periodic B.C. on non-periodic geometries
3. Two simple models of chemical degradation
4. Heuristic relation coupling elastic moduli and permeability

Context

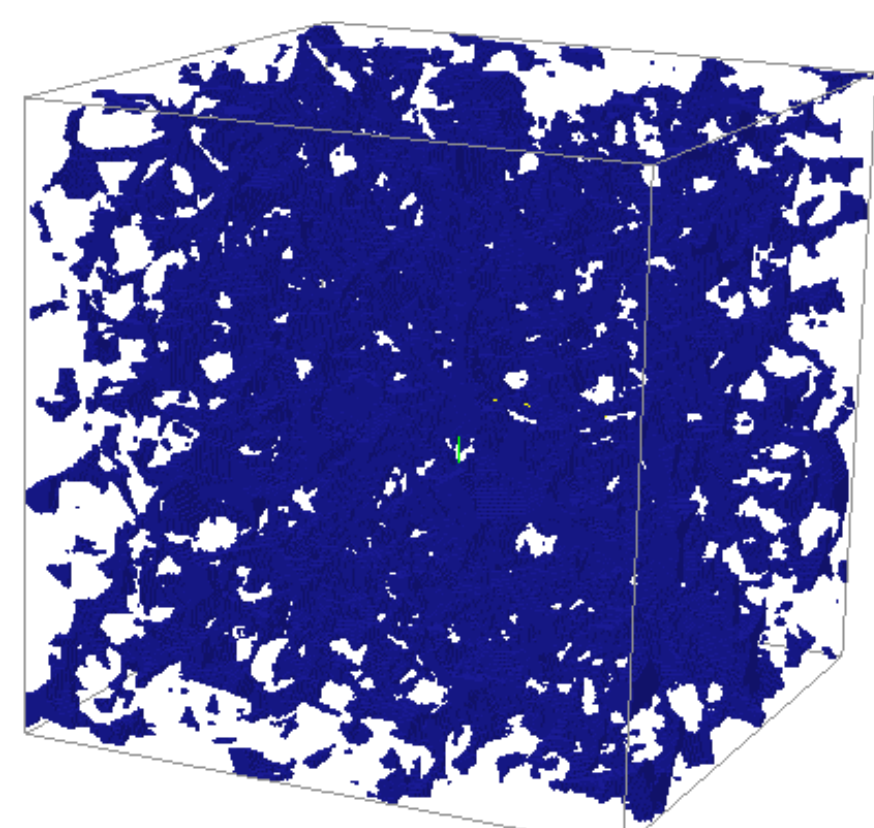
Carbon Capture and Storage (CCS) consists of injecting large quantities of CO₂ in supercritical form directly into deeply located geological formations e.g. saline aquifers. During geological storage, **chemical dissolution** induces important and irreversible changes of the rock properties.

Objective is to propose a **methodology** which allows us to predict the evolution of effective mechanical behaviour of saline aquifers caused by microstructural changes due to **CCS**.

Advanced Morphological Analysis of Sandstone

The **starting point** is **CT scan** of microstructure of **Fontainebleau sandstone** of size 256x256x256 px, where 1 px = 5.01 microns.

Numerous types of morphological descriptors: porosity, sizing (granulometry), covariance function, connectivity (tortuosity).

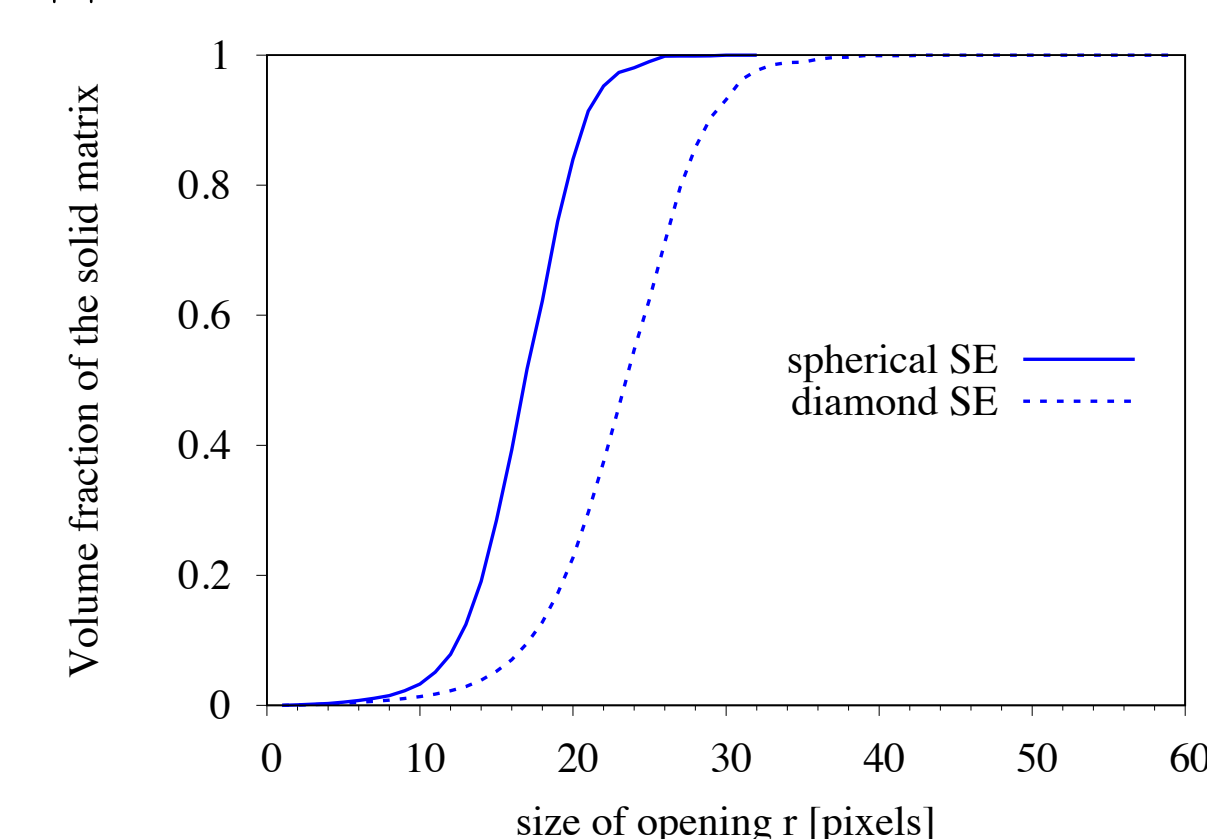


[Tomography - pores]

Granulometry Function

$$G_r(X) = 1 - \frac{|X \circ B_r|}{|X|}$$

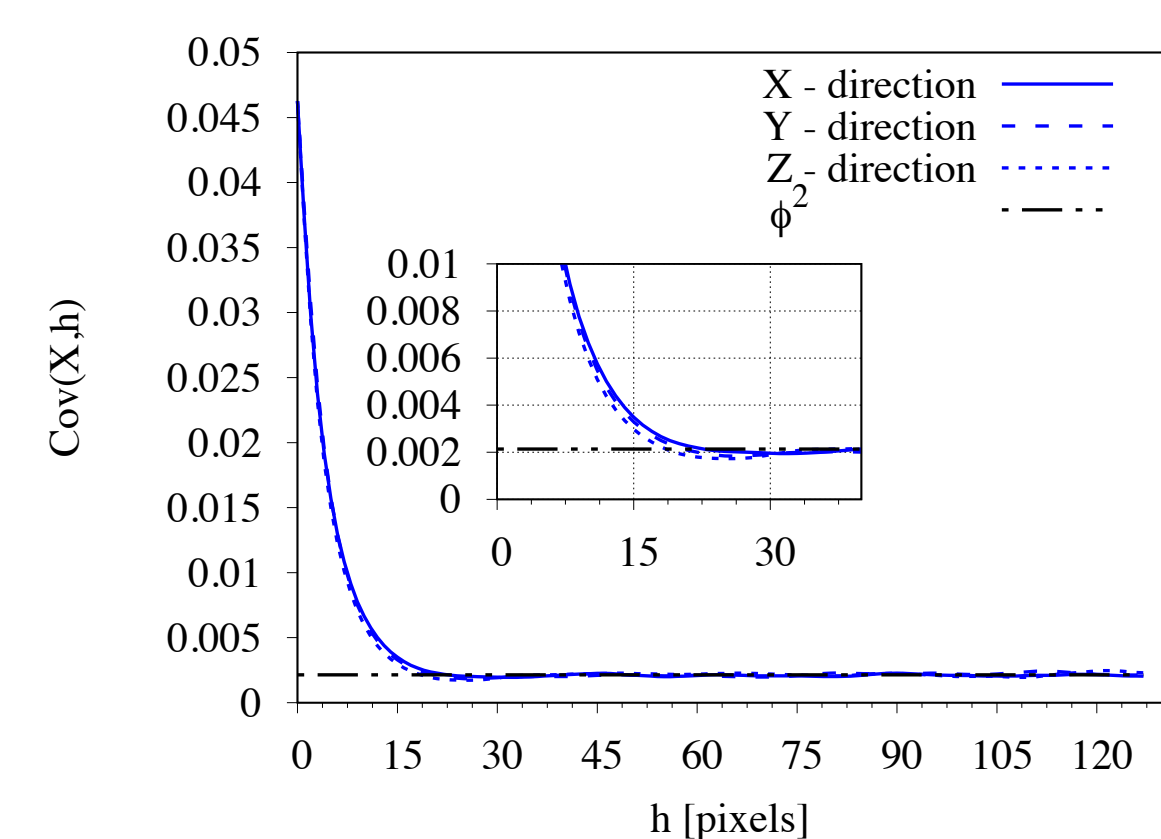
X – solid phase
 B_r – structuring element of size r
 $X \circ B_r = (X \ominus B_r) \oplus B_r$
 \ominus / \oplus – erosion / dilation
 $|\cdot|$ – measure



Covariance Function

$$C(X, \vec{h}) = P \{ x \in X, x + \vec{h} \in X \}$$

$P\{\cdot\}$ – probability
 X – porous phase
 x – arbitrary point
 \vec{h} – translation vector

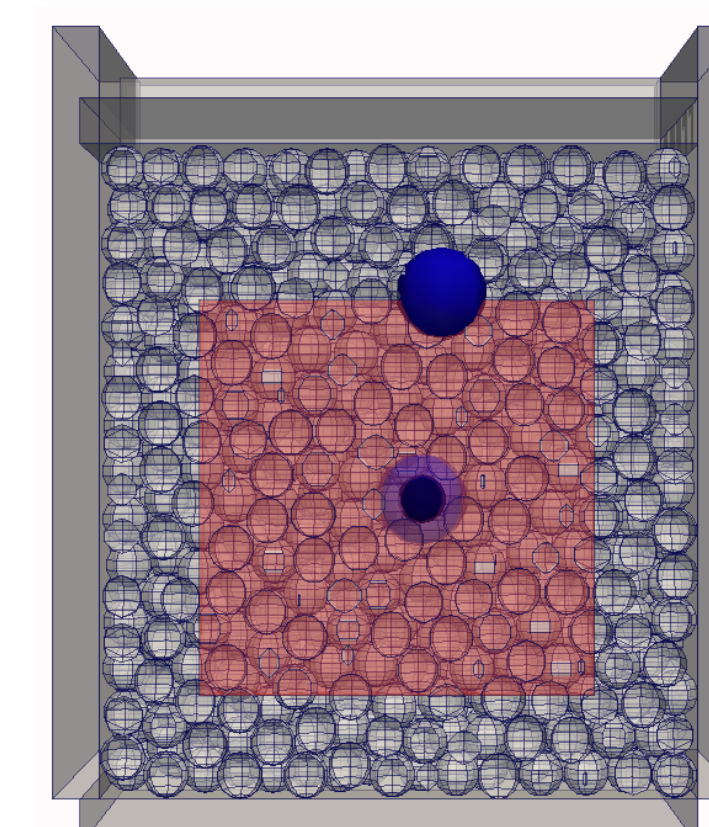


Summary: $\varphi = 0.046$ $\varphi_{eff} = 0.029$ percolated in all directions $r_{mean} \in (17, 23)$ isotropy

Numerical Samples - Generation

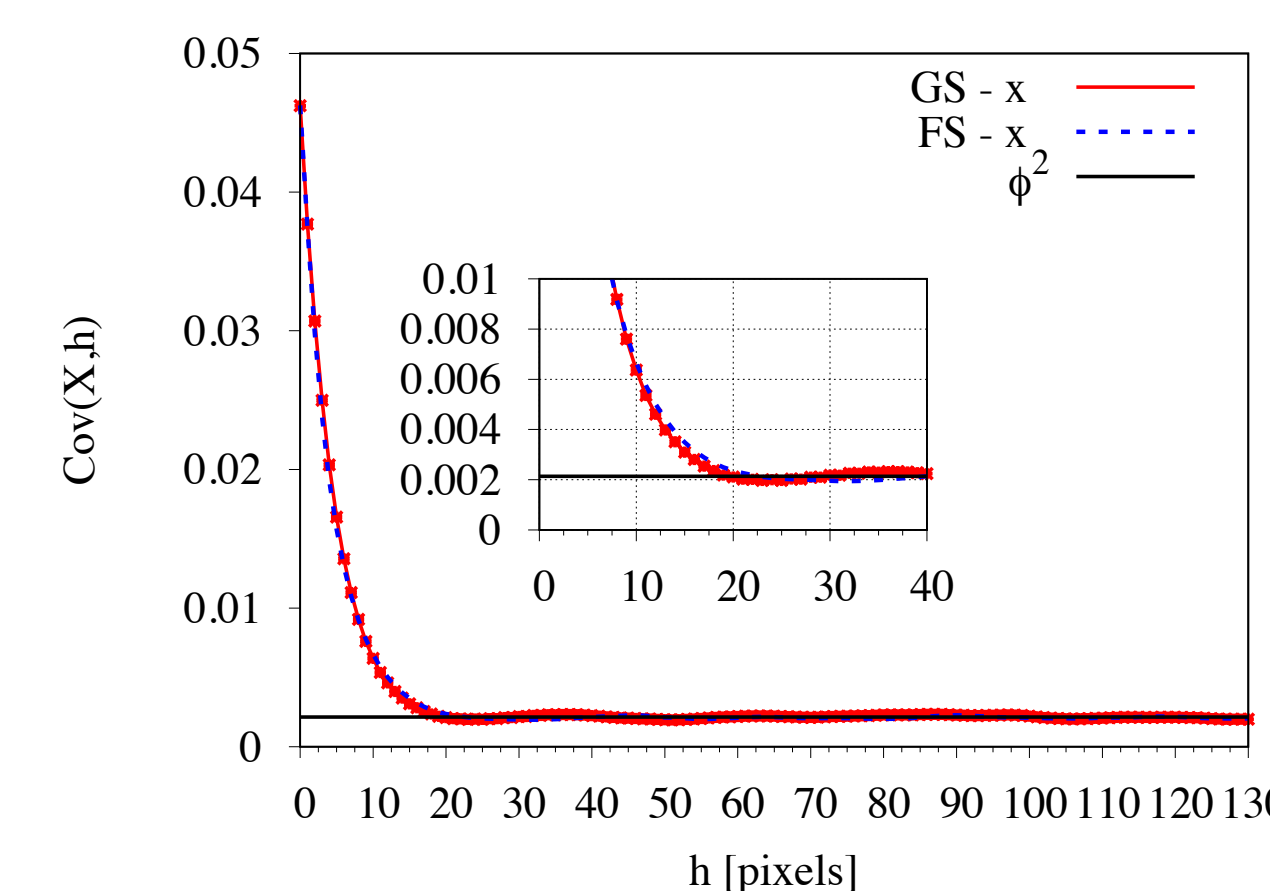
The method is inspired by natural formation process of sandstones [Bakke and Øren, 1997] and adjusted in order to respect aforementioned morphological properties:

1. **grain deposit** - monodisperse grains assembly of initial radius 14 px, deposited into 3D box,
2. **triaxial compaction** - bulk volume reduction,
3. **diagenesis** - mixed uniform and random radii increment to obtain desired value of porosity.

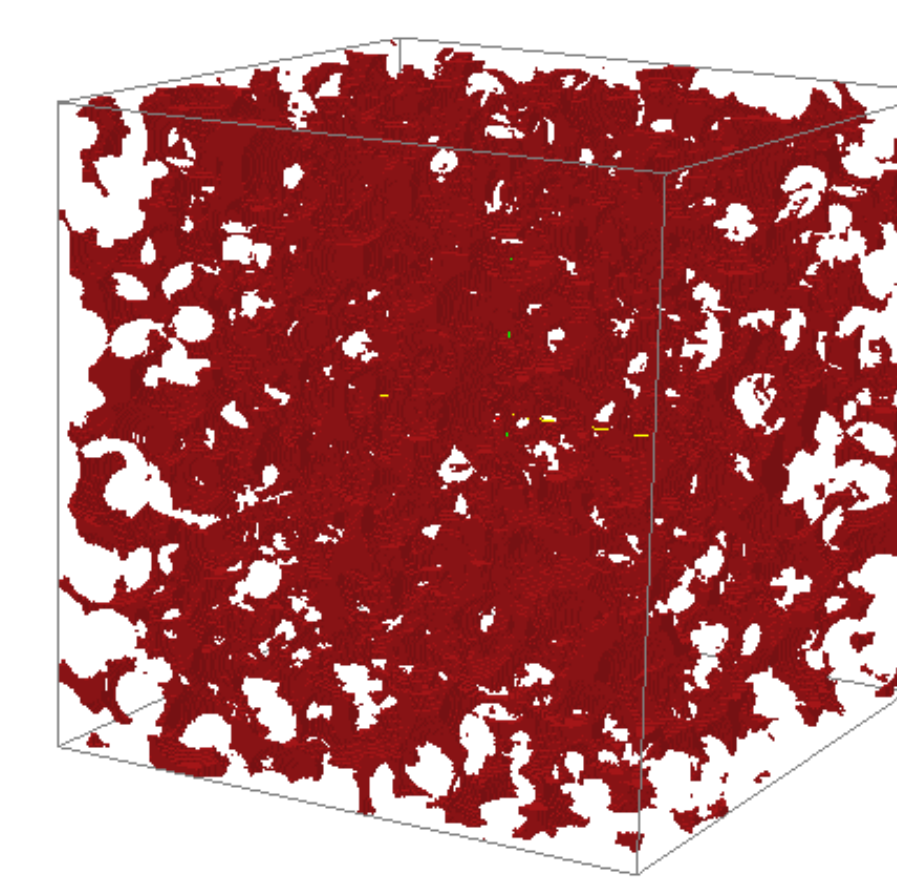


[Reconstruction method]

Generated samples (red box) are validated **a posteriori**.



[Comparison of covariance functions]



[Generated microstructure]

Numerical Dissolution by Morphological Dilation

Chemical dissolution of porous matrix is homogeneous at sample scale [Egermann et al, 2006]. We investigate two different scenarii of dissolution:

Isotropic

$$X_i = X_{i-1} \oplus B$$

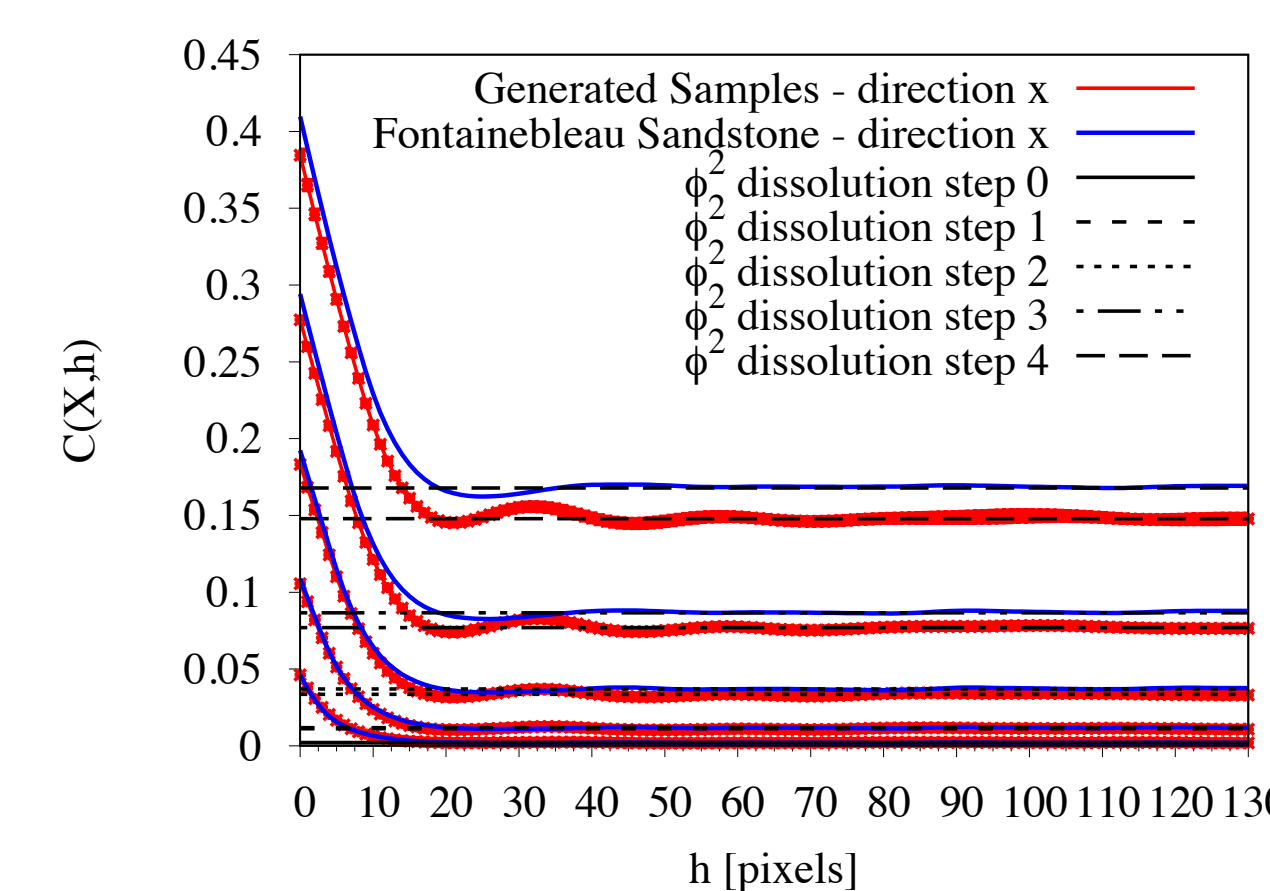
X_0 – binary image representing initial porous phase

X_i – binary image of i -th dissolution step

\oplus – morphological dilation

B – cubic SE (3x3)

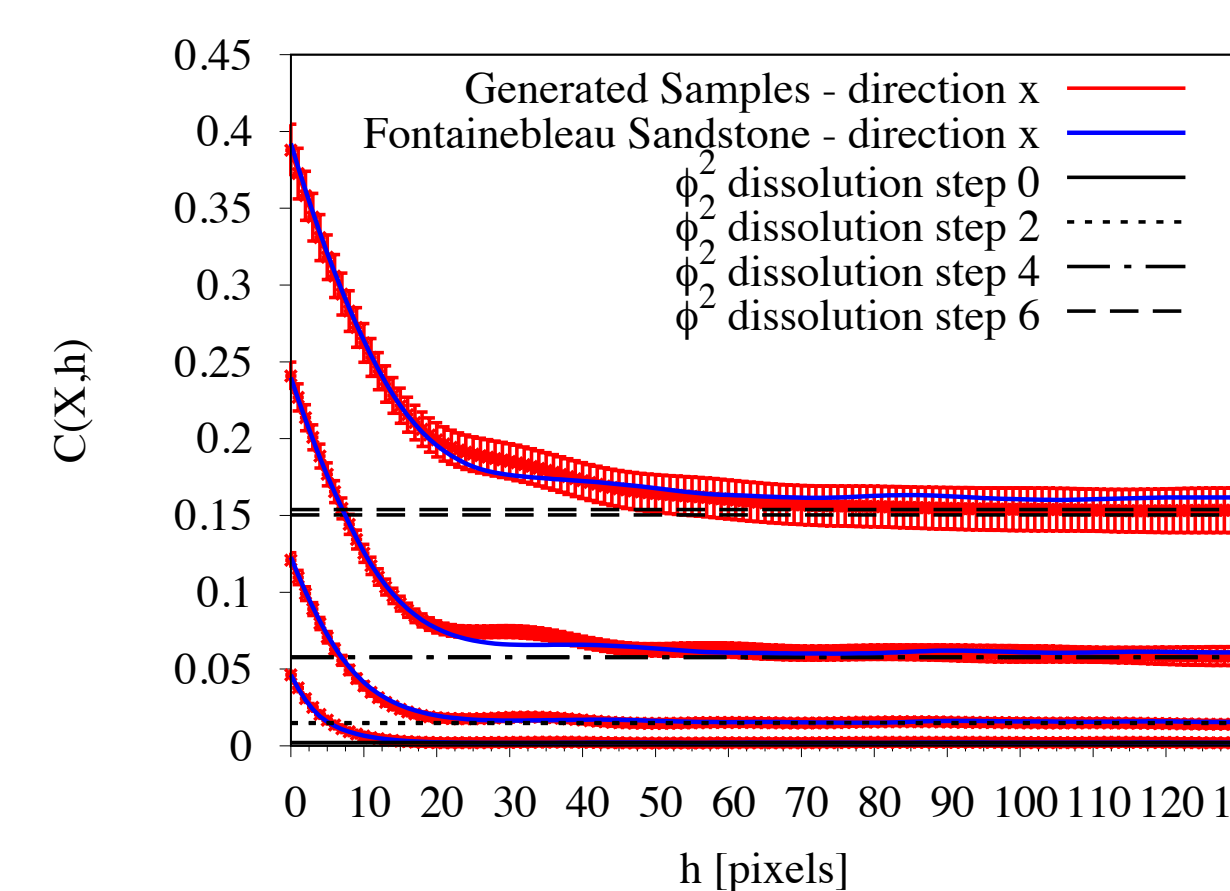
$\Xi(\cdot)$ – operator extracting percolated network



[Evolution of covariance functions of generated samples (red) and real microstructure (blue)]

Percolated Network

$$X_i = [\Xi(X_{i-1}) \oplus B] + X_0$$



Constant characteristic size

Increasing characteristic size

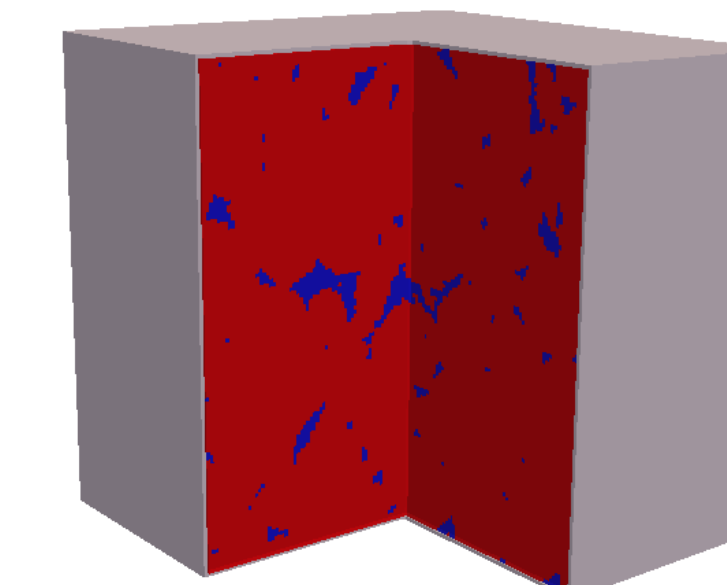
Elasticity - Periodic Homogenization

Method of numerical, periodic homogenisation:

problem: non-periodic geometry.

solution: additional layer of homogeneous material associated with

fixed point method: $c_{klmn}^{layer}[i] = c_{klmn}^{hom}[i - 1]$

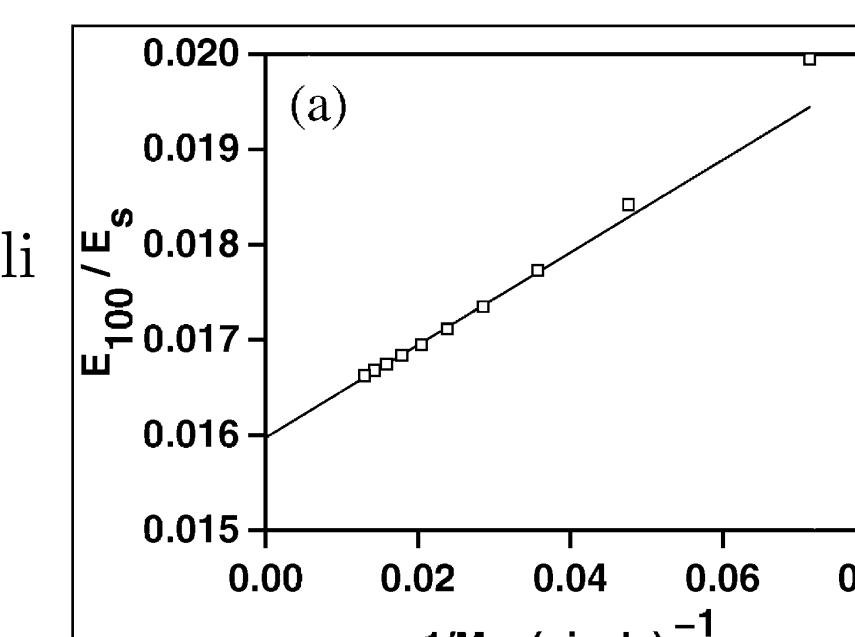


[External layer]

CT scan is naturally discretised (regular cubic mesh).

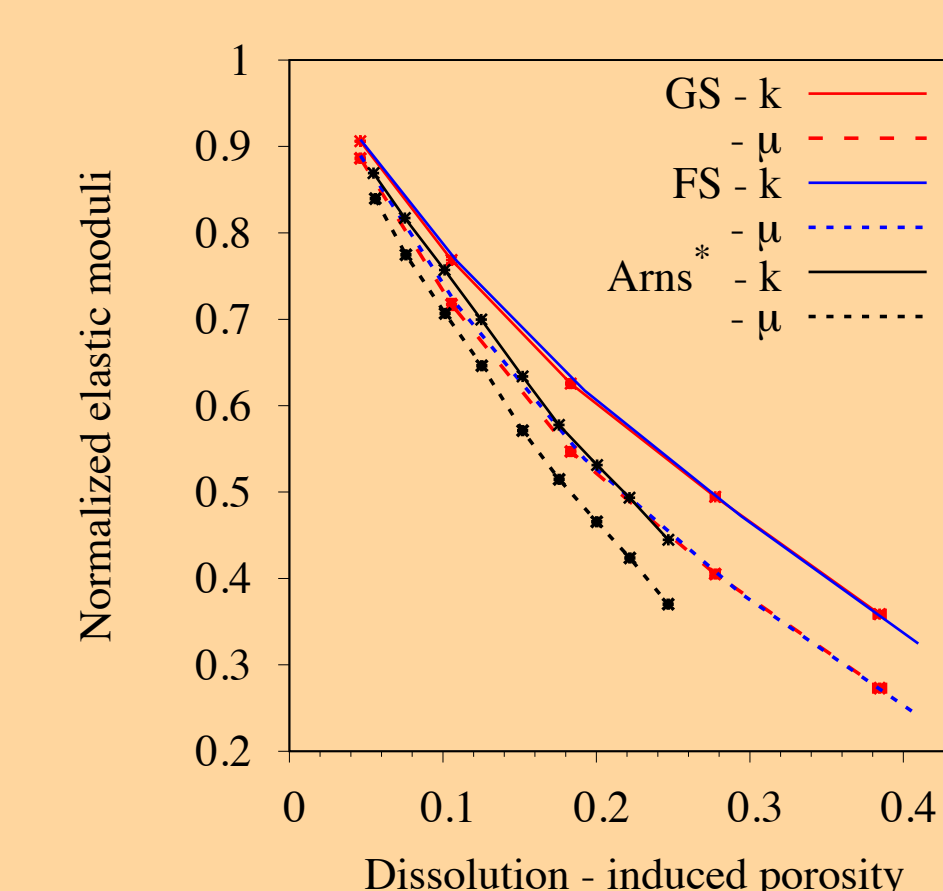
The influence of such discretization on the estimation of elastic moduli is given by [Garboczi and Day, 1995]:

$$P(M) = P_0 + \frac{a}{M} \quad \begin{matrix} P(\cdot) - \text{computed elastic moduli} \\ M - \text{resolution} \\ P_0 - \text{searched value} \end{matrix}$$

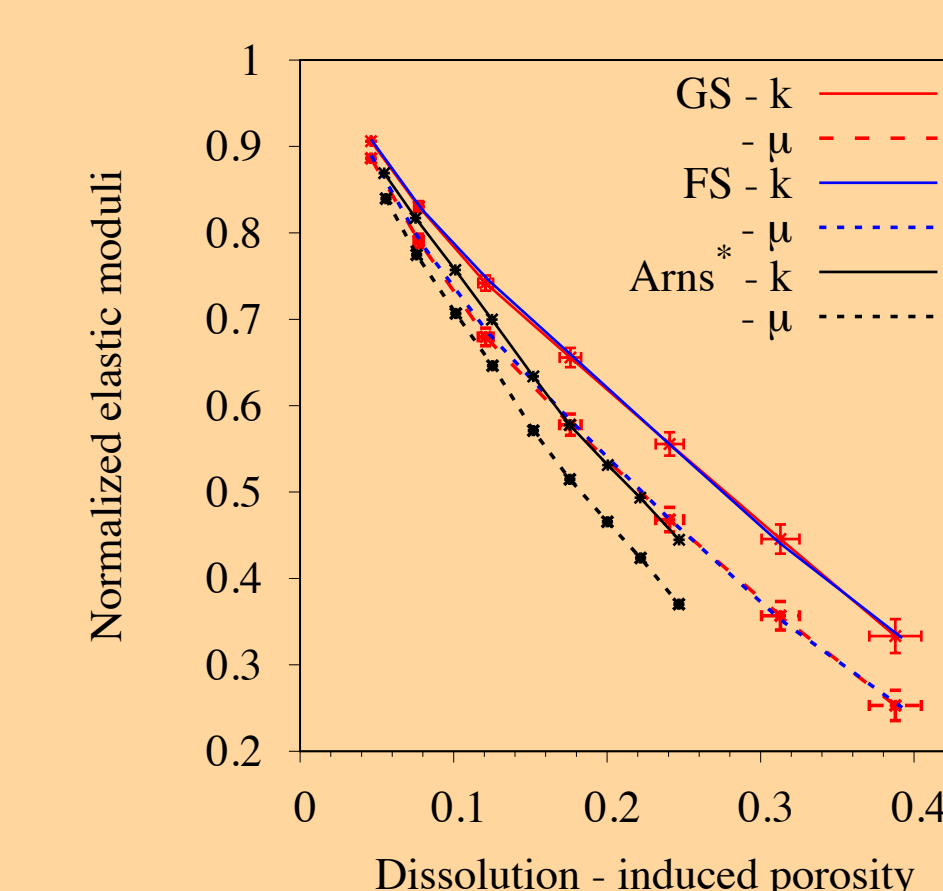


[Roberts and Garboczi, 2002]

Isotropic dissolution



Percolated network dissolution



* Arns et al. 2002

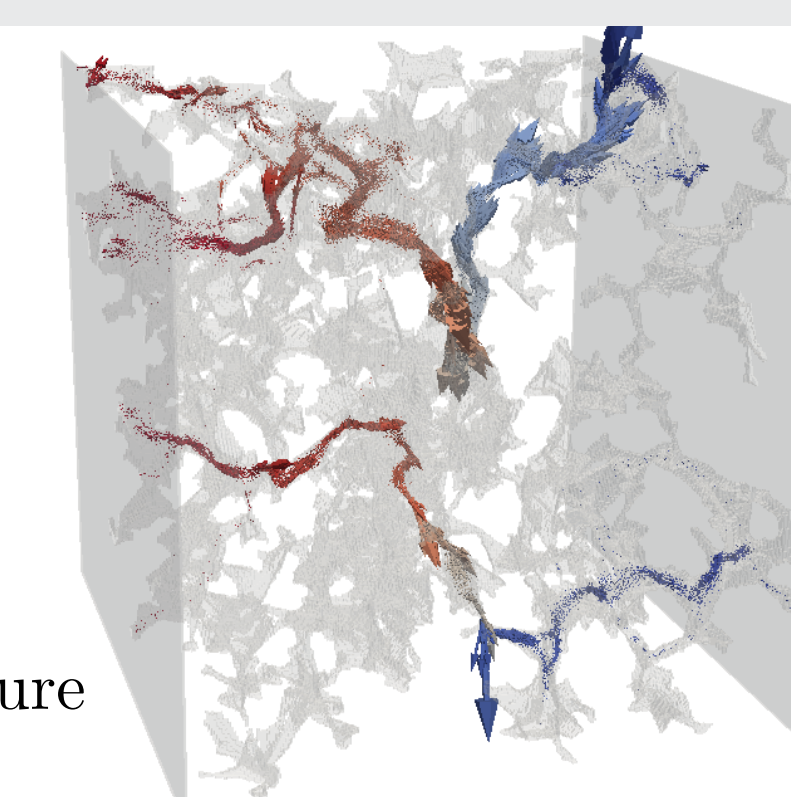
Permeability - Elasticity Coupling

Darcy's law: $K = \frac{\mu Q L}{\Delta p A}$

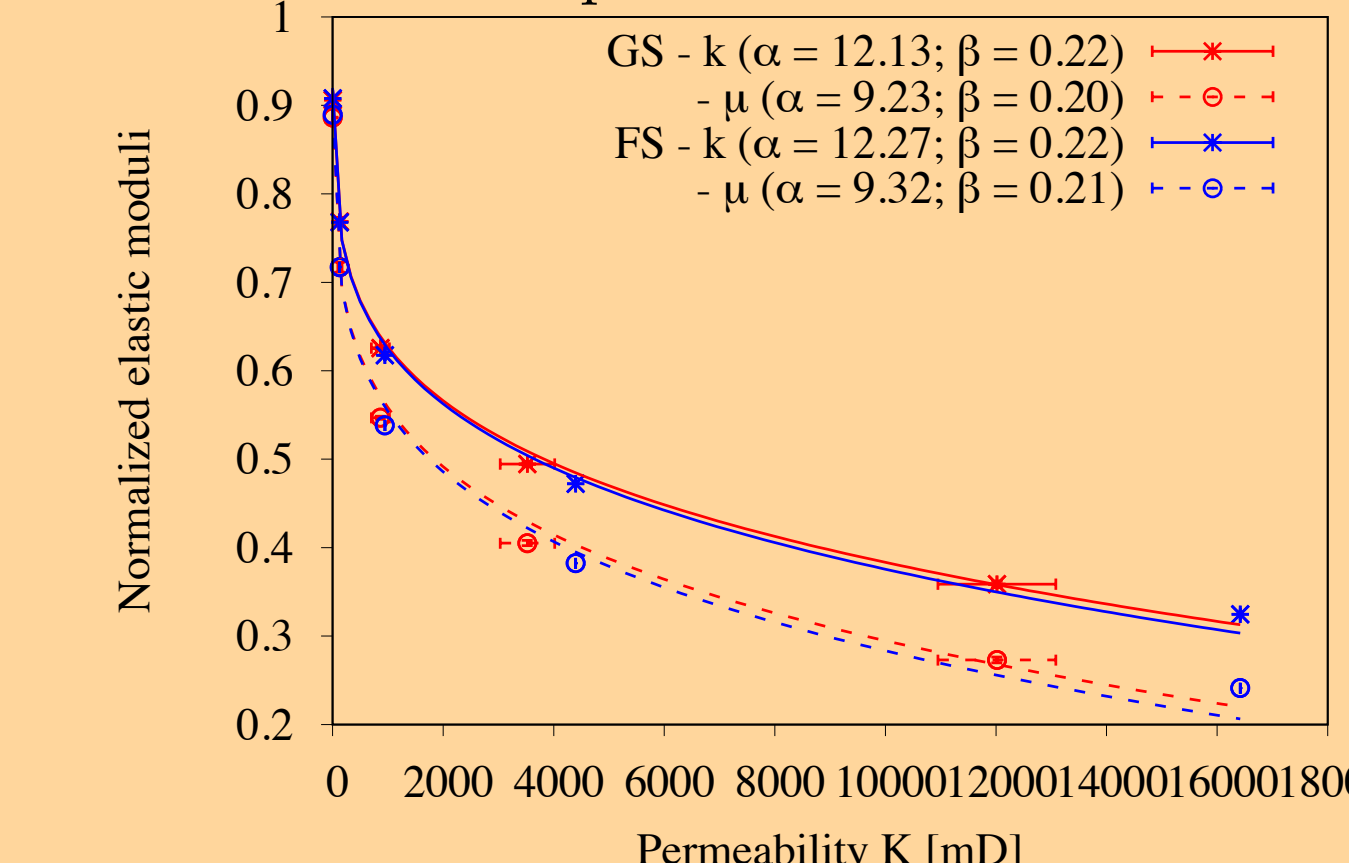
K – permeability
 μ – dyn. viscosity
 Q – flux
 A – surface area

Coupling: $P(K) = 1 - \frac{K^\beta}{\alpha}$

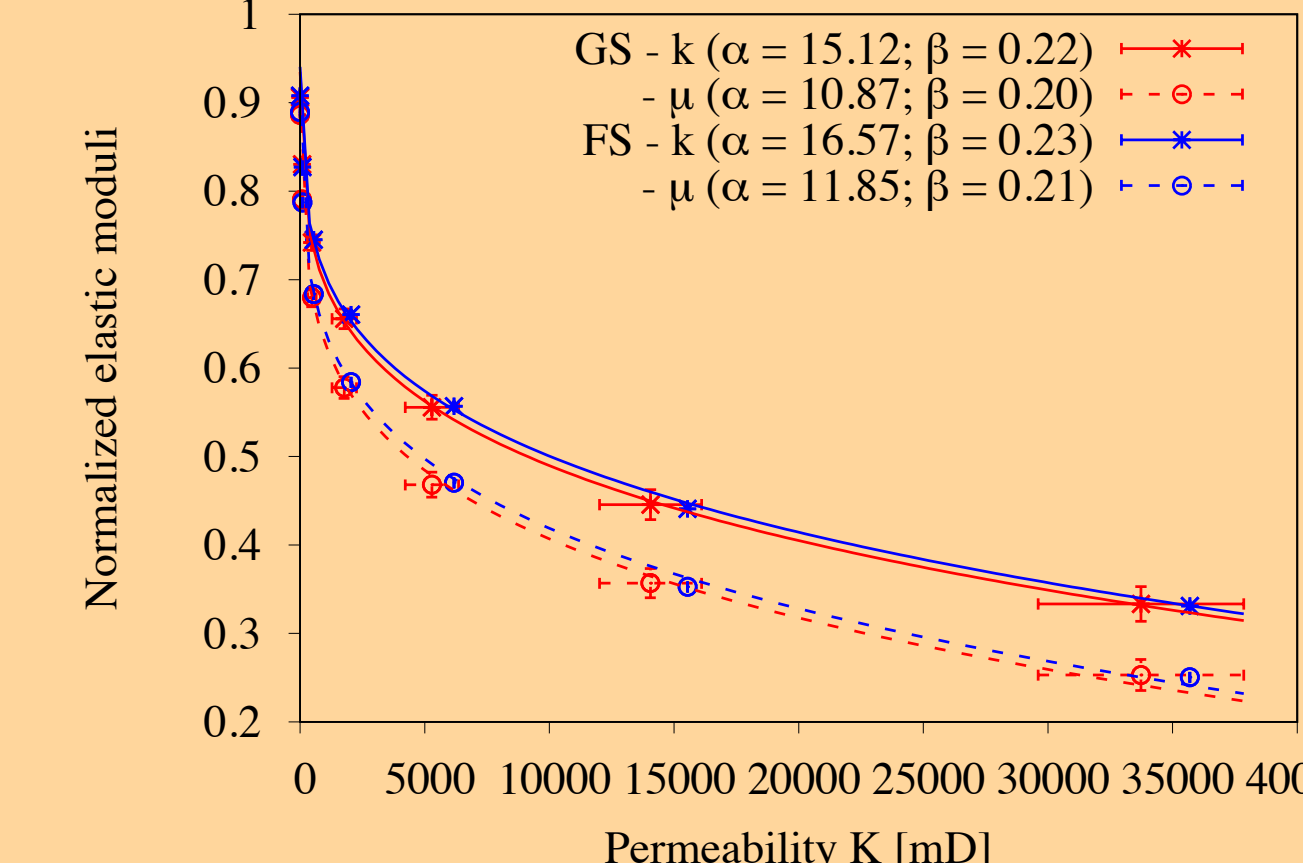
L – sample length
 Δp – grad. of pressure



Isotropic dissolution



Percolated network dissolution



* kajetan.wojtacki@umontpellier.fr

