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

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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

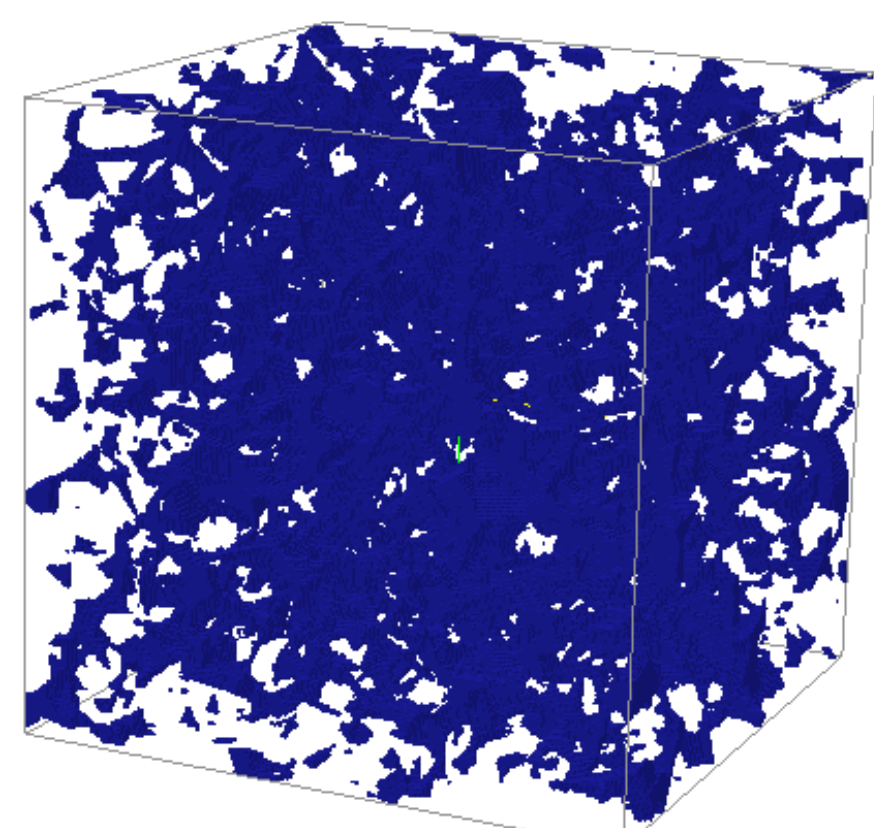
Carbon Capture and Storage (CCS) consists of injecting large quantities of CO₂ in supercritical form directly into deeply located geological formations e.g. saline aquifers. During geological storage, **chemical dissolution** induces important and irreversible changes of the rock properties.

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).

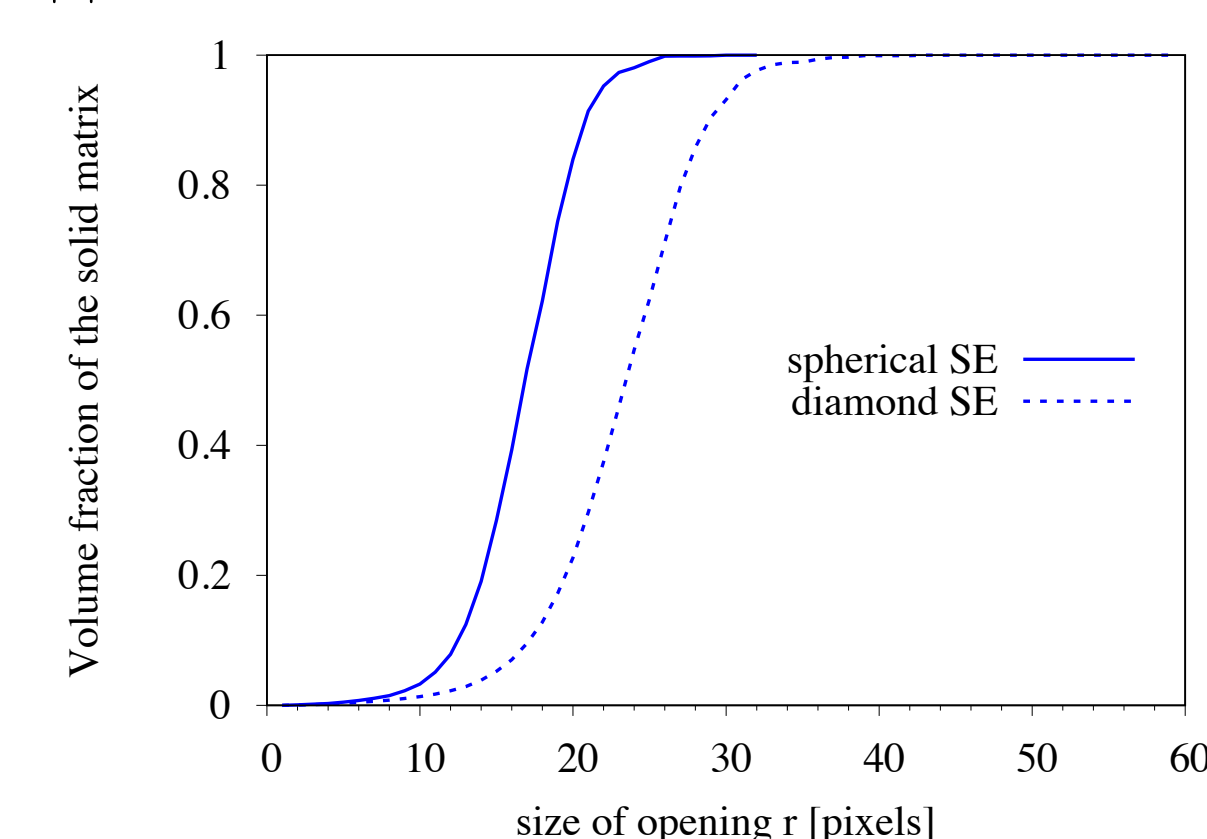


[Tomography - pores]

Granulometry Function

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

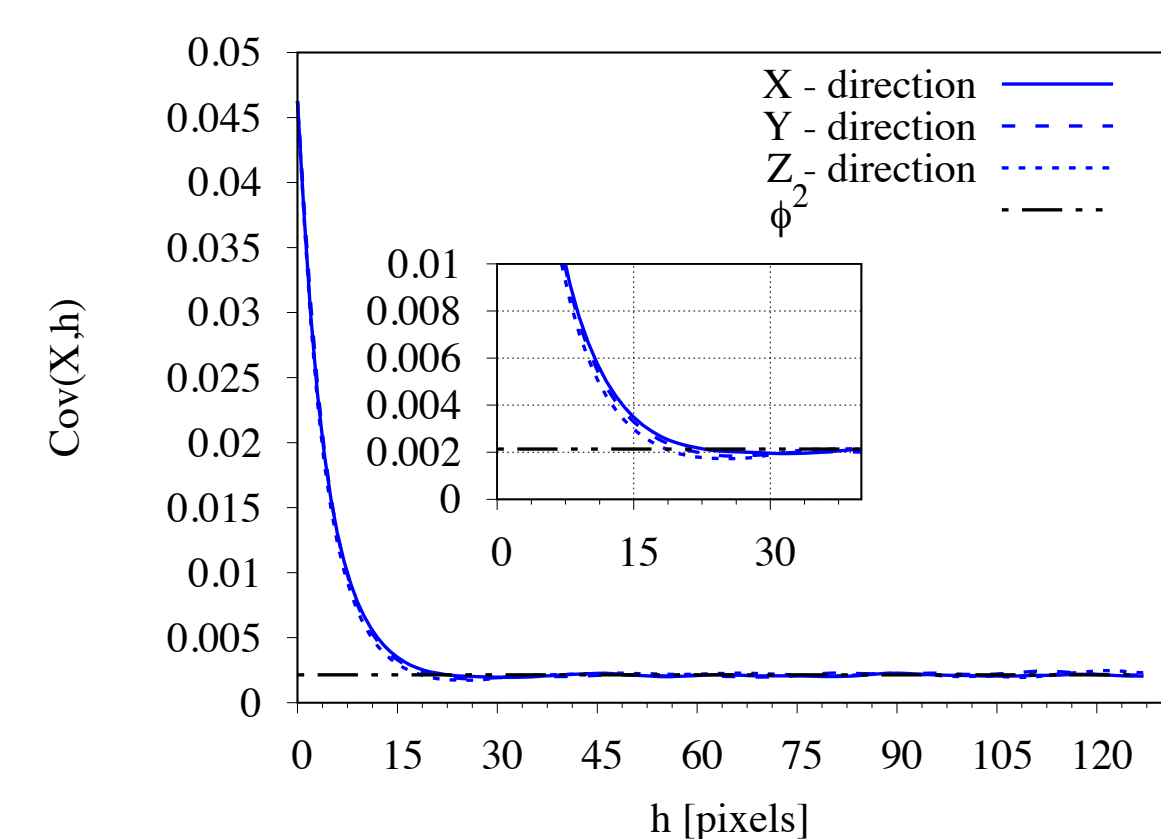
X – solid phase
 B_r – structuring element of size r
 $X \circ B_r = (X \ominus B_r) \oplus B_r$
 \ominus / \oplus – erosion / dilation
 $|\cdot|$ – measure



Covariance Function

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

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

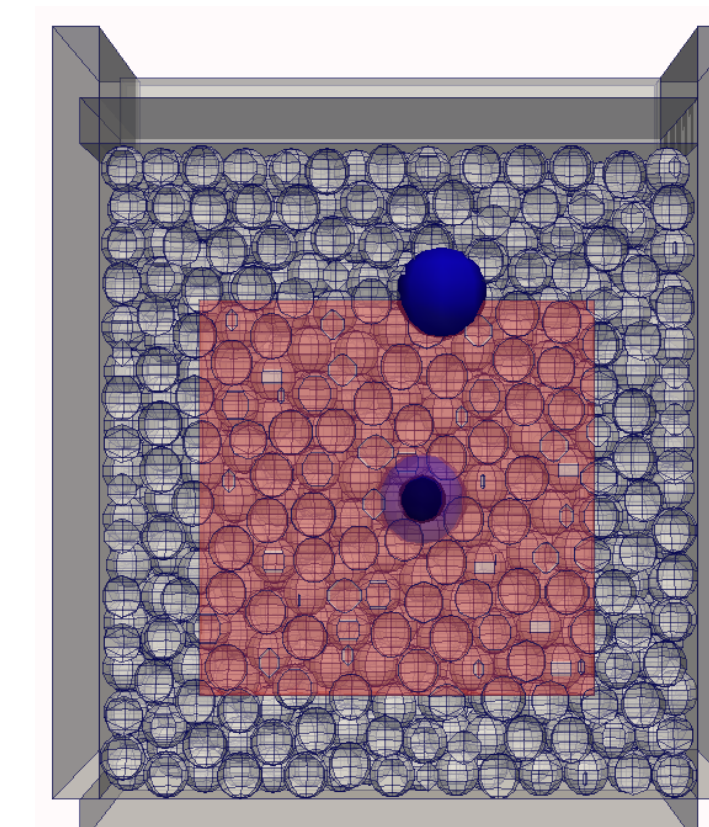


Summary: $\varphi = 0.046$ $\varphi_{eff} = 0.029$ percolated in all directions $r_{mean} \in (17, 23)$ isotropy

Numerical Samples - Generation

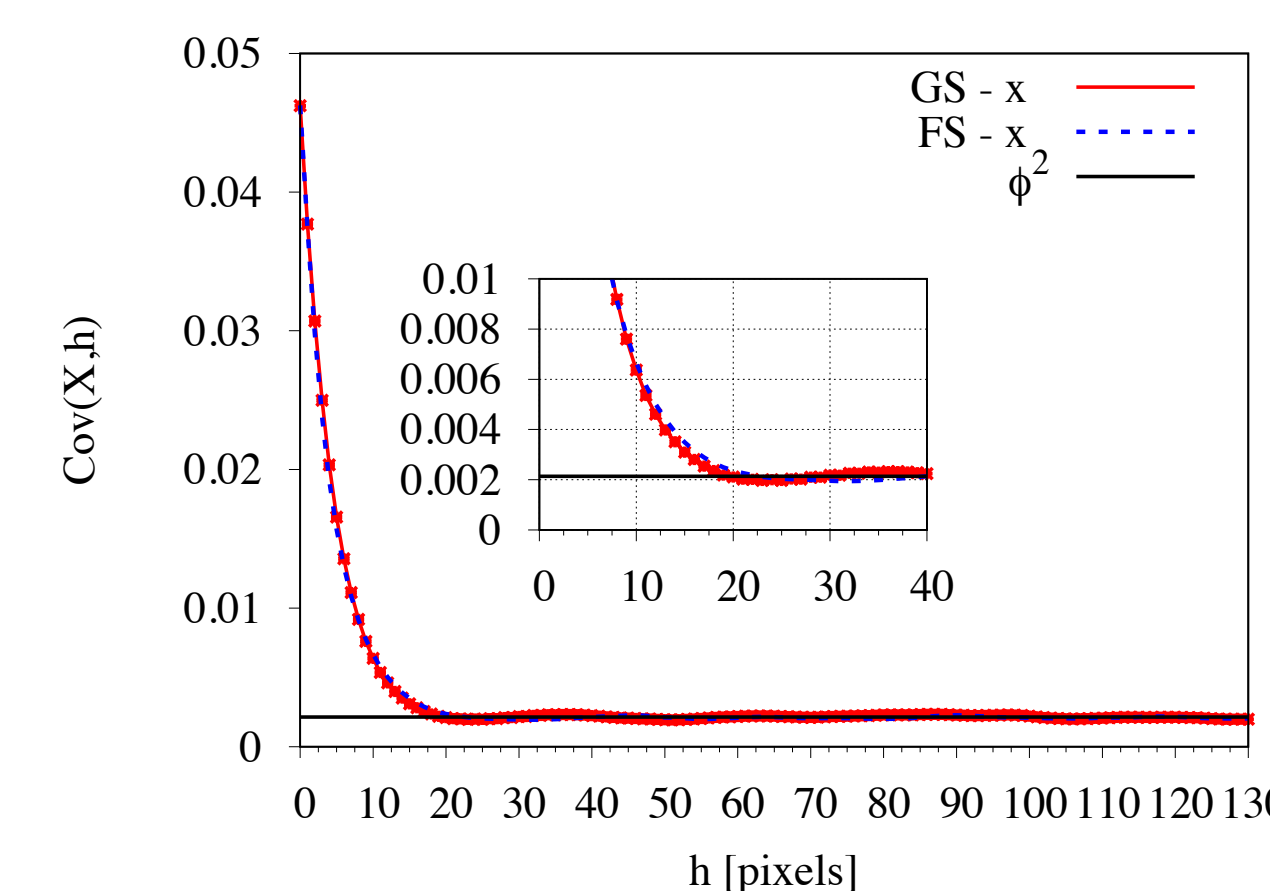
The method is inspired by natural formation process of sandstones [Bakke and Øren, 1997] and adjusted in order to respect aforementioned morphological properties:

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.

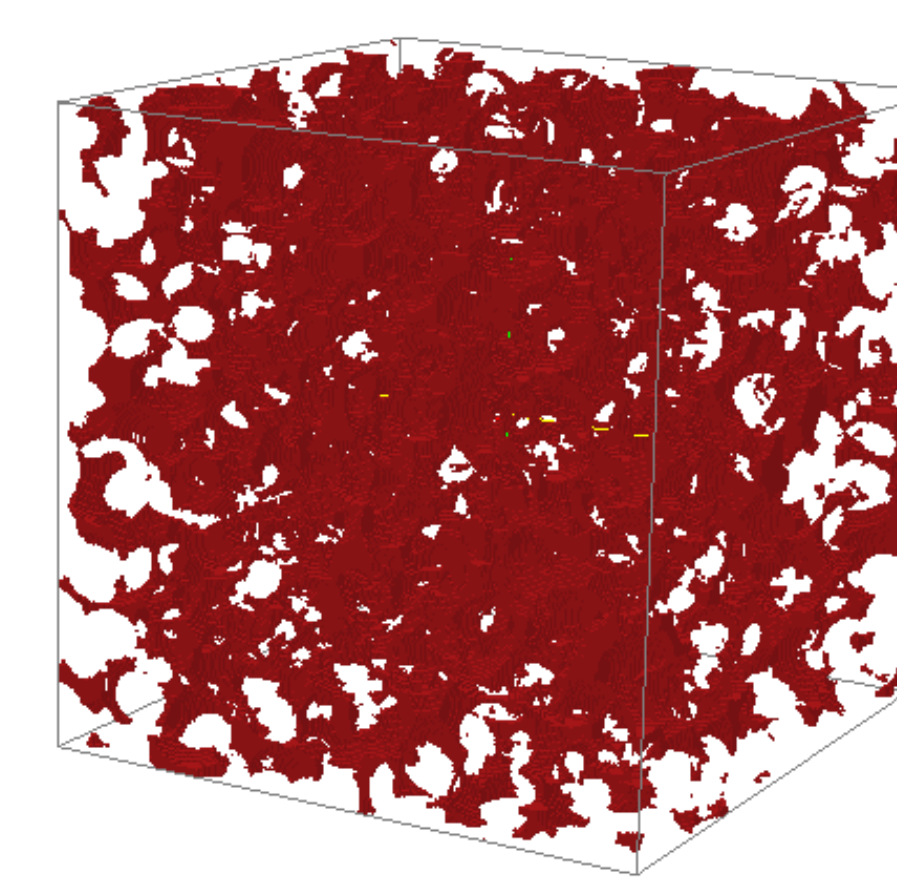


[Reconstruction method]

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

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

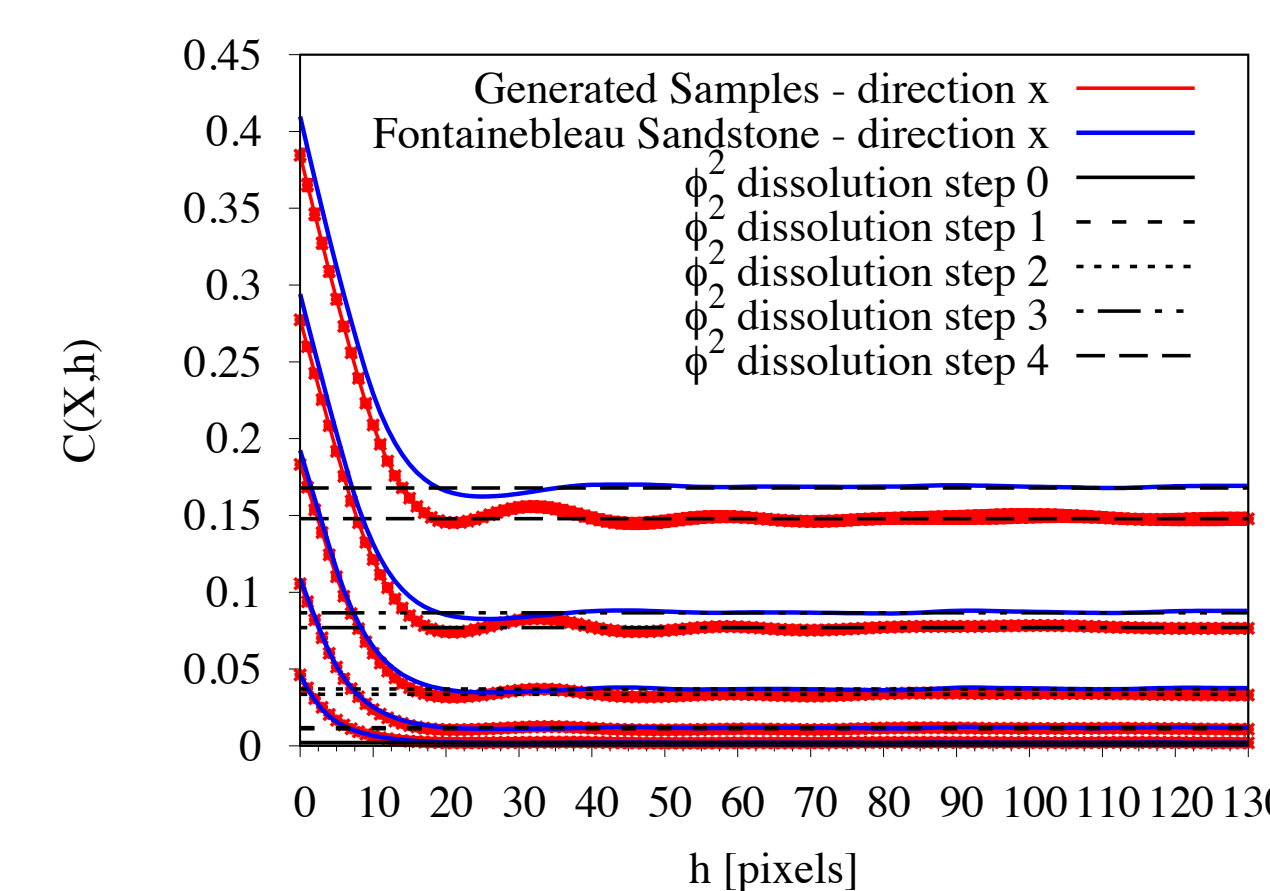
X_0 – binary image representing initial porous phase

X_i – binary image of i -th dissolution step

\oplus – morphological dilation

B – cubic SE (3x3)

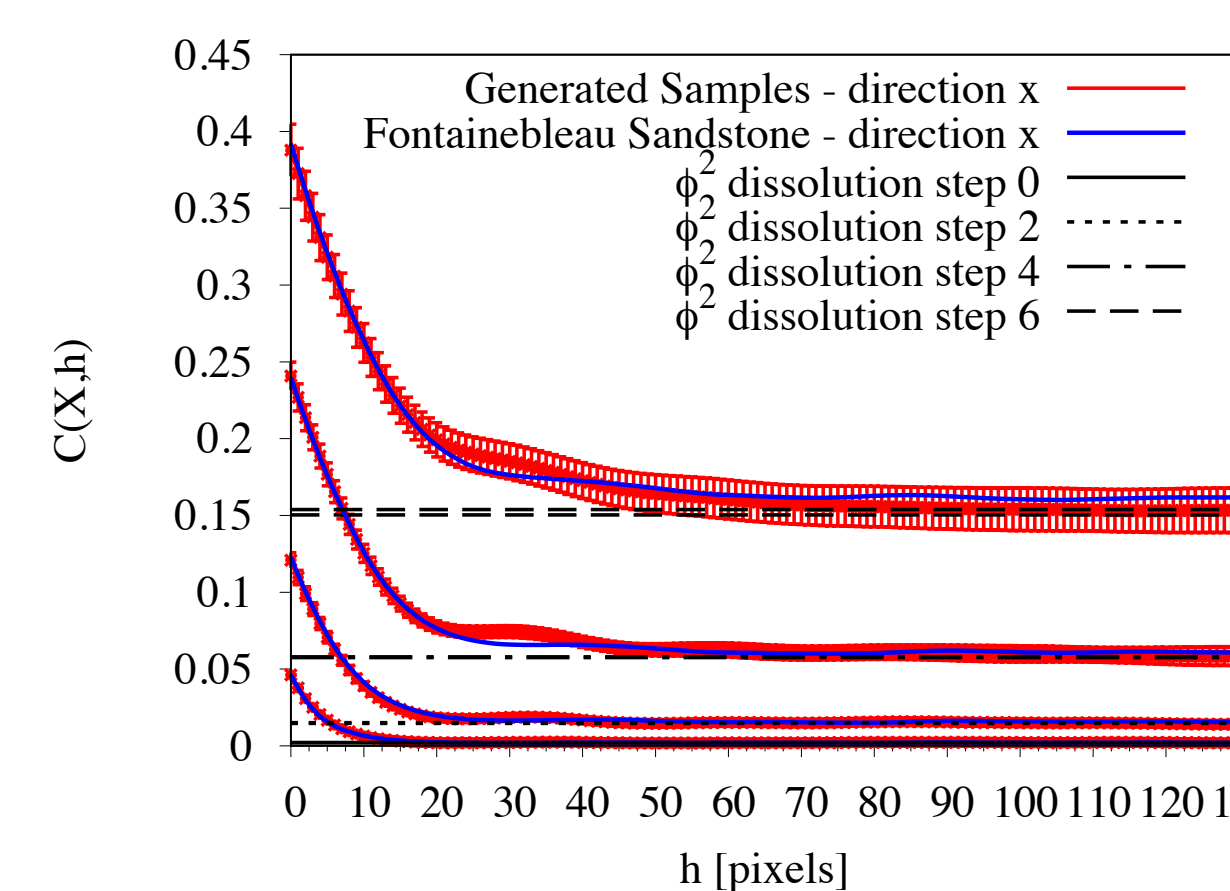
$\Xi(\cdot)$ – operator extracting percolated network



[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

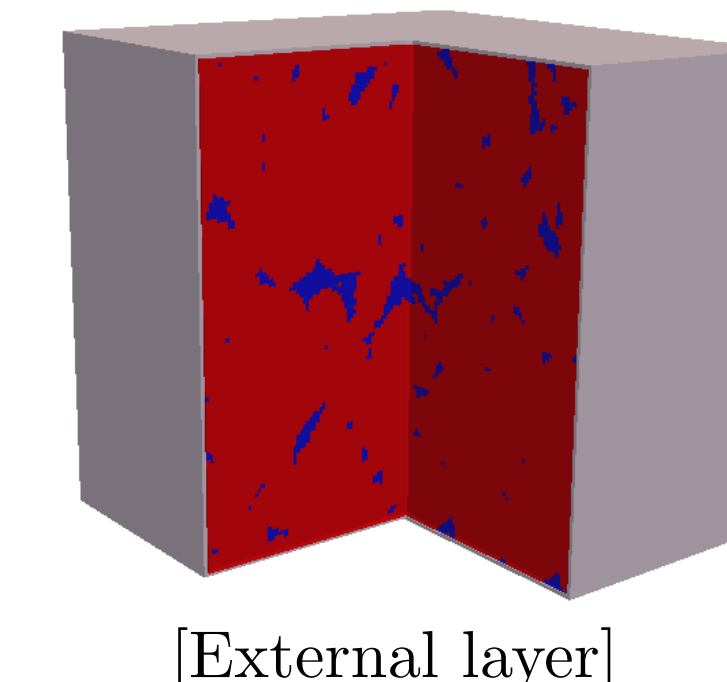
Elasticity - Periodic Homogenization

Method of numerical, periodic homogenisation:

problem: non-periodic geometry.

solution: additional layer of homogeneous material associated with

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

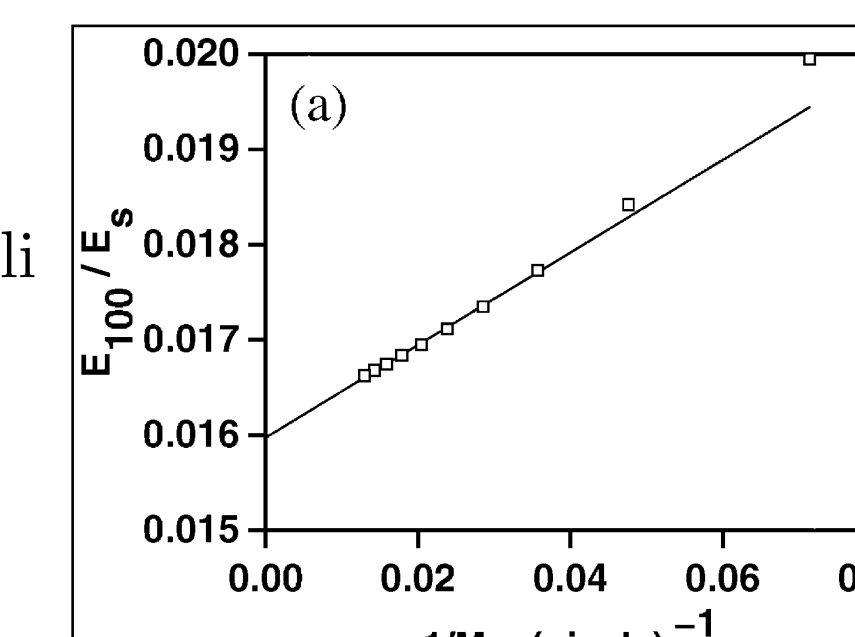


[External layer]

CT scan is naturally discretised (regular cubic mesh).

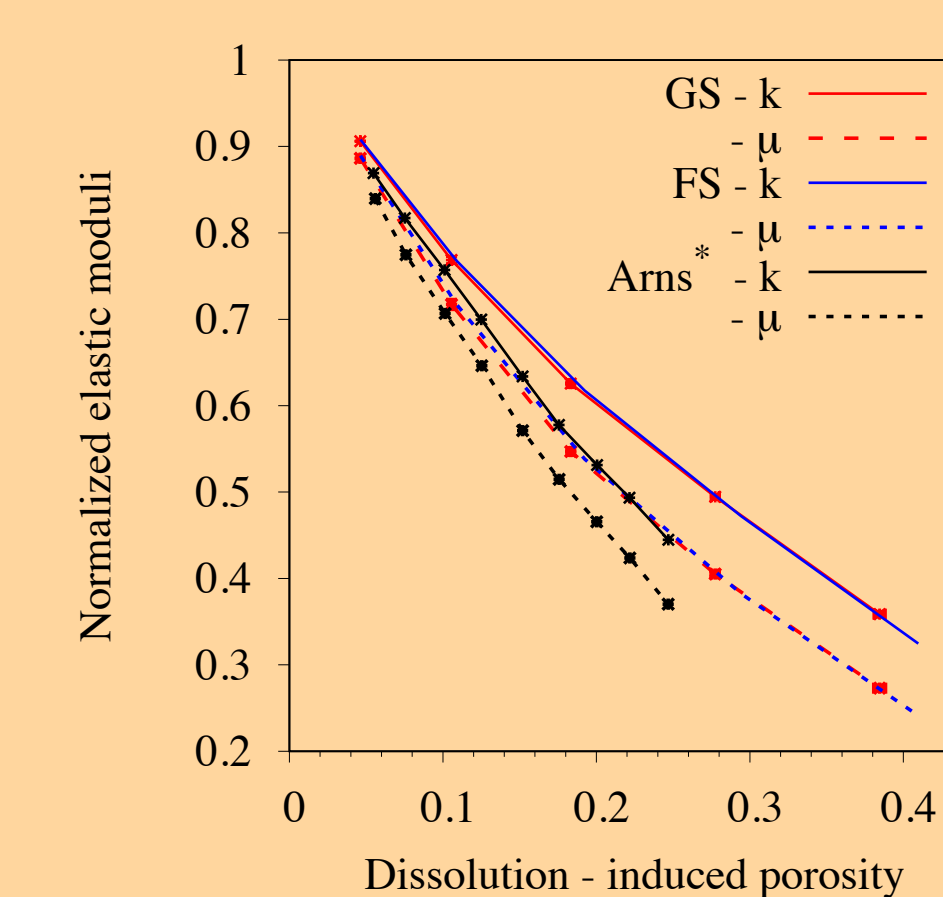
The influence of such discretization on the estimation of elastic moduli is given by [Garboczi and Day, 1995]:

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

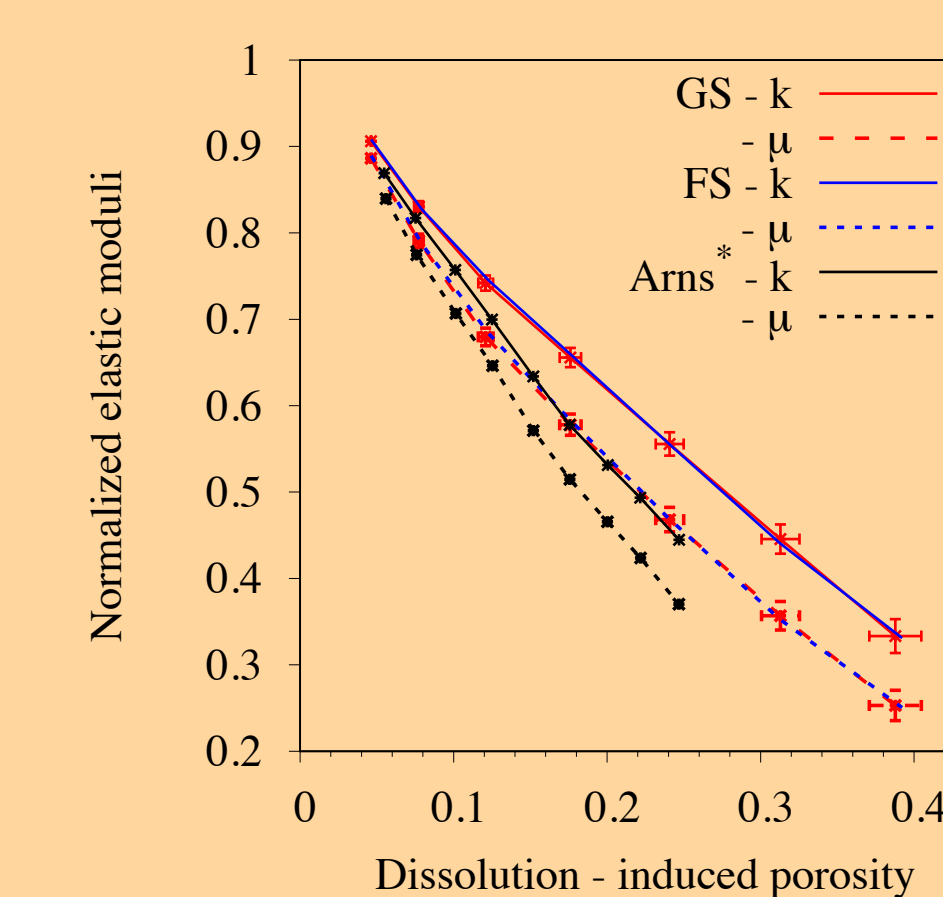


[Roberts and Garboczi, 2002]

Isotropic dissolution



Percolated network dissolution



* Arns et al. 2002

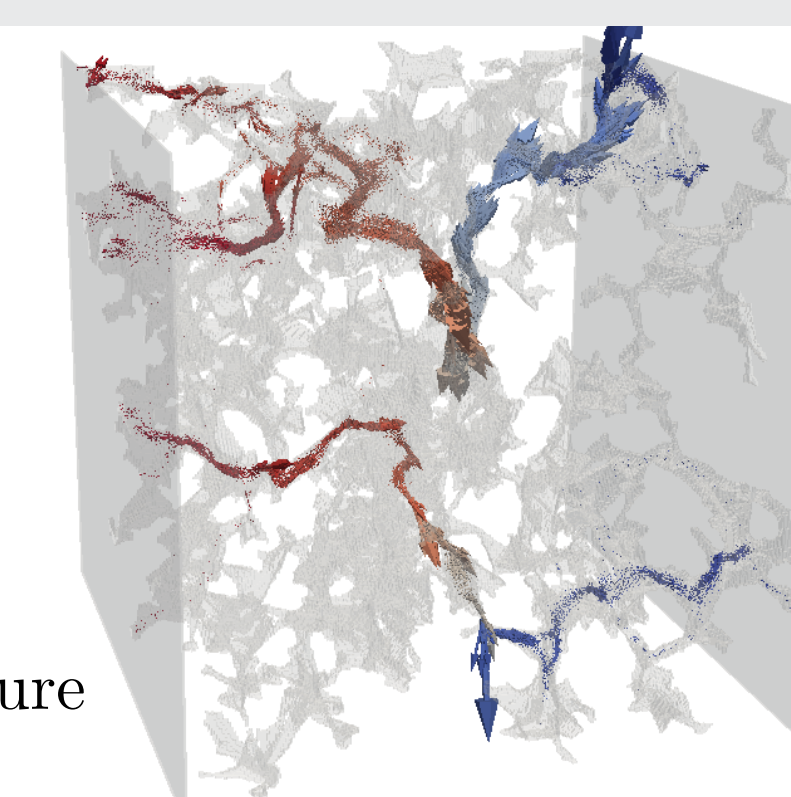
Permeability - Elasticity Coupling

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

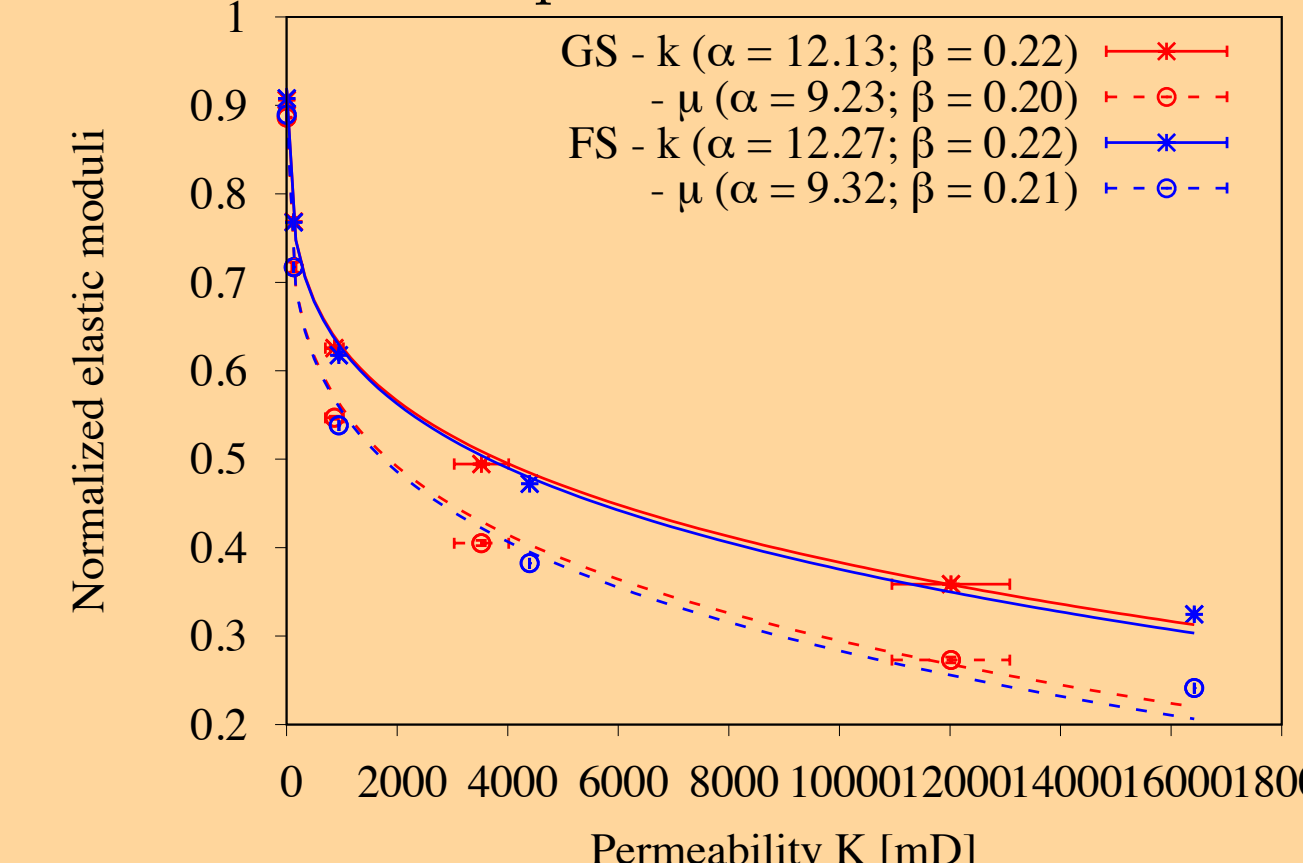
K – permeability
 μ – dyn. viscosity
 Q – flux
 A – surface area

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

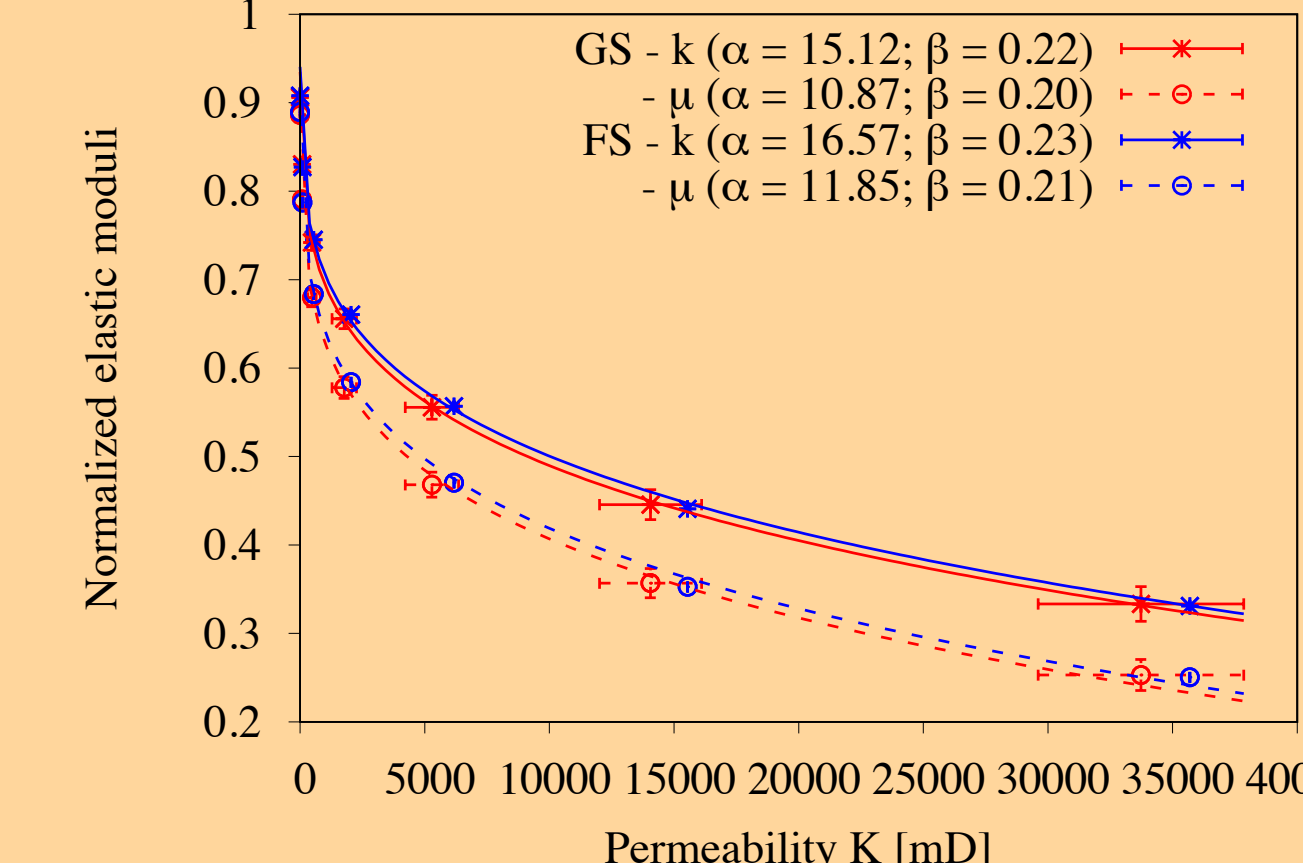
L – sample length
 Δp – grad. of pressure



Isotropic dissolution



Percolated network dissolution



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