Chemical degradation of a numerical material - Application to a Fontainbleau sandstone

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

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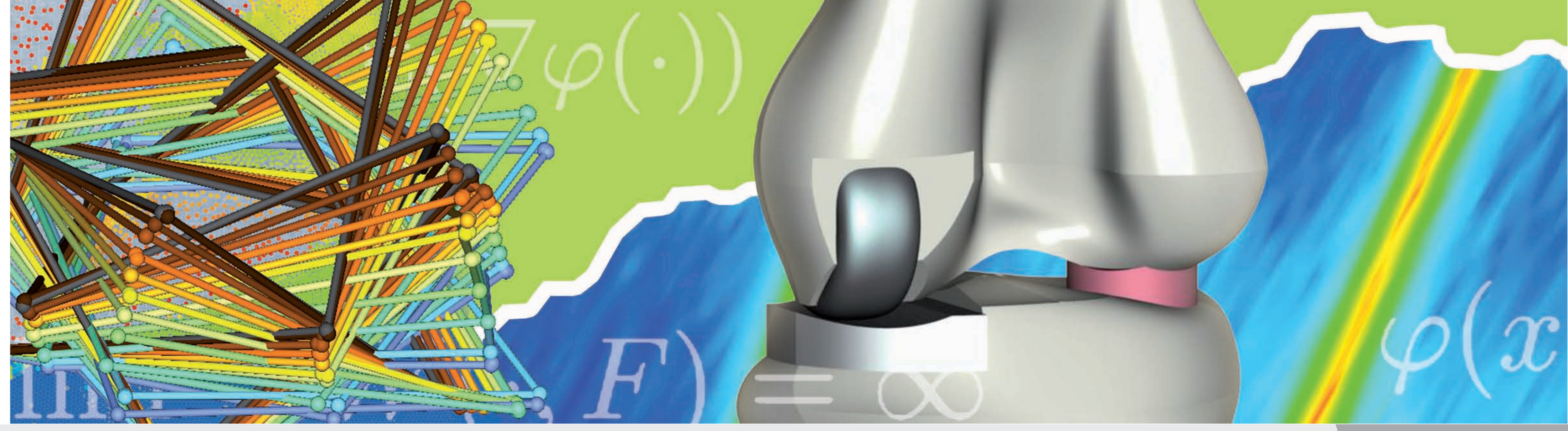


Highlights

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

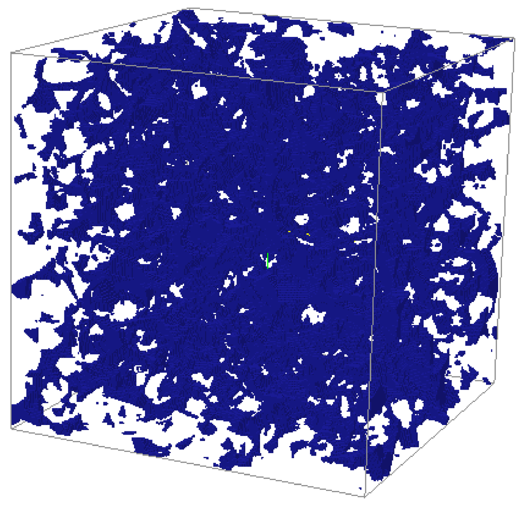
Carbon Capture and Storage (CCS) consists of injecting large quantities of CO_2 in supercritical form directly into deeply located geological formations e.g. saline aquifers. During geological storage, **chemical dissolution** induces important and irreversible changes of the rock properties.

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 256x256x 256 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

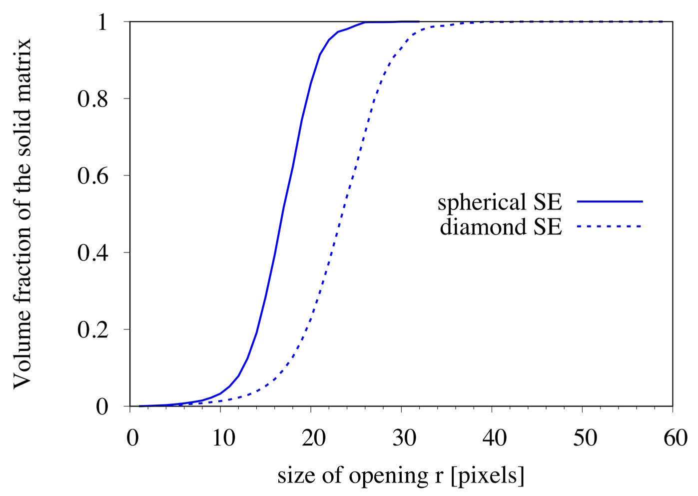
$$C(X, \vec{h}) = P\left\{x \in X, x + \vec{h} \in X\right\}$$

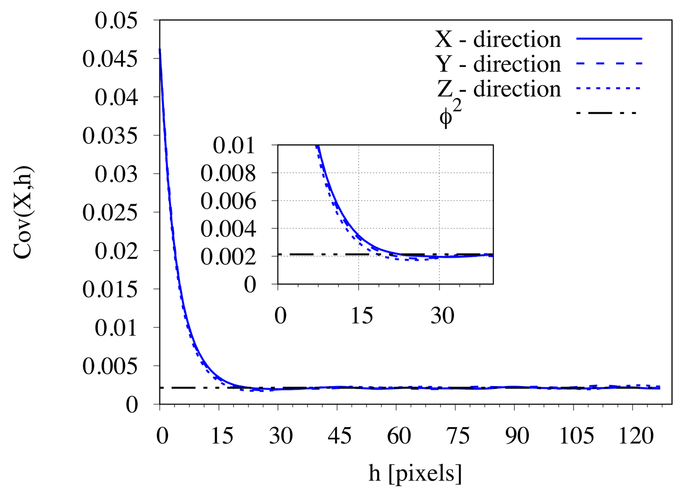
$P\{\cdot\}$ – probability

X – porous phase

x – arbitrary point

$\vec{h}$ – translation vector



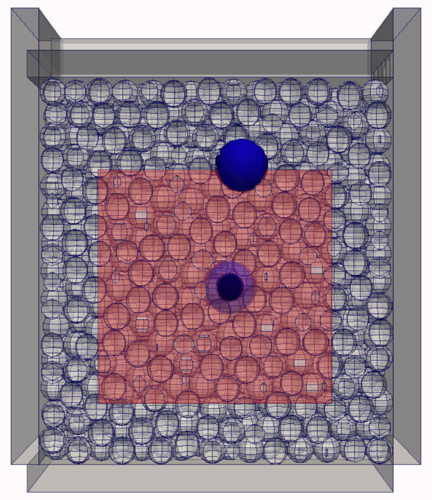


Summary: $\varphi = 0.046$ $\varphi_{eff} = 0.029$ percolated in all directions $r_{mean} \in (17, 23)$ isotropy

Numerical Samples - Generation

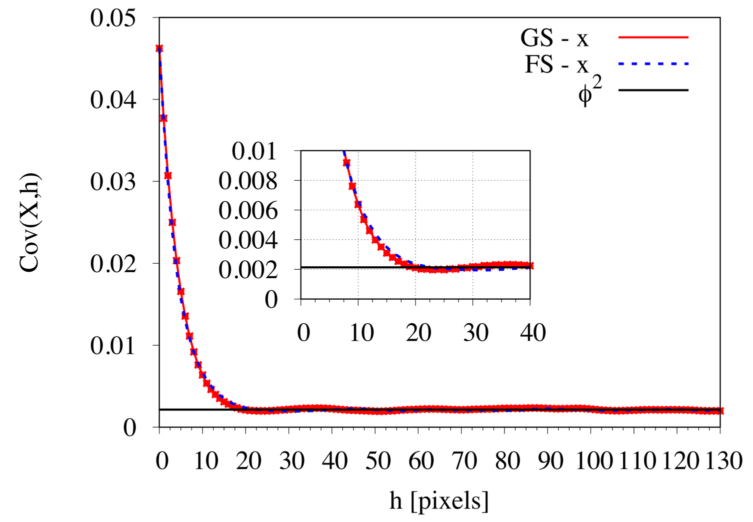
The method is inspired by natural formation process of sandstones [Bakke and Øren, 1997] and adjusted in order to respect aforementioned morphological properties:

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

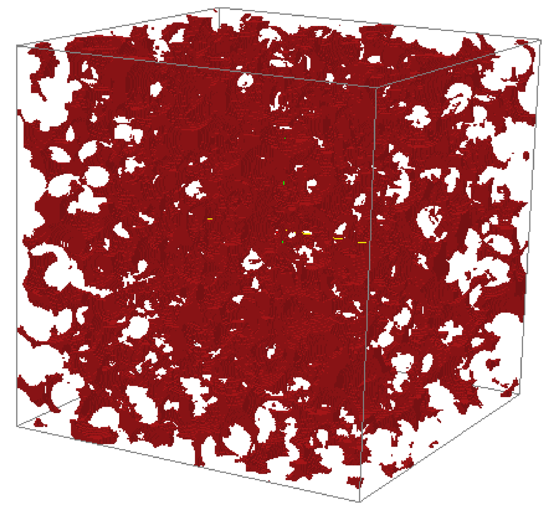


[Reconstruction method]

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

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

Percolated Network

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

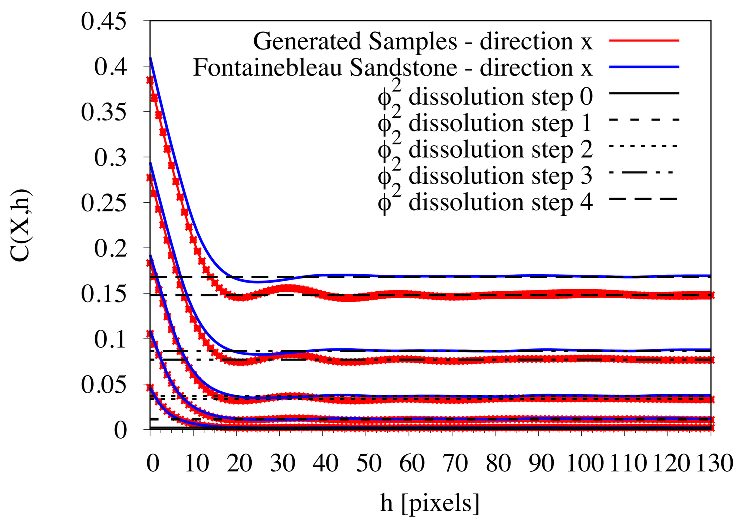
X_0 – binary image representing initial porous phase

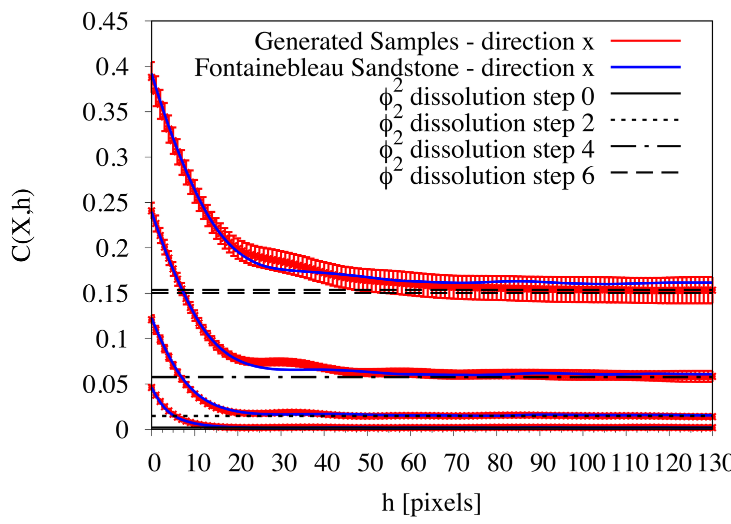
X_i – binary image of i-th dissolution step

$\oplus$ – morphological dilation

B – cubic SE (3x3)

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





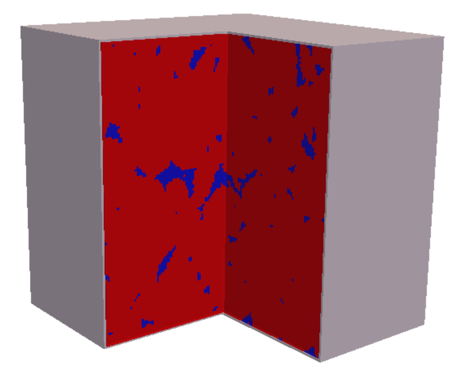
[Evolution of covariance functions of generated samples (red) and real microstructure (blue)]

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: $c^{layer}_{klmn}[i] = c^{hom}_{klmn}[i-1]$



[External layer]

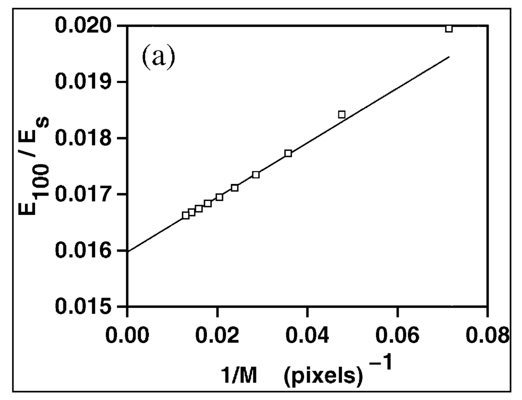
CT scan is naturally discretised (regular cubic mesh). The influence of such discretization on the estimation of elastic moduli is given by [Garboczi and Day, 1995]:

$$P(M) = P_0 + \frac{a}{M}$$

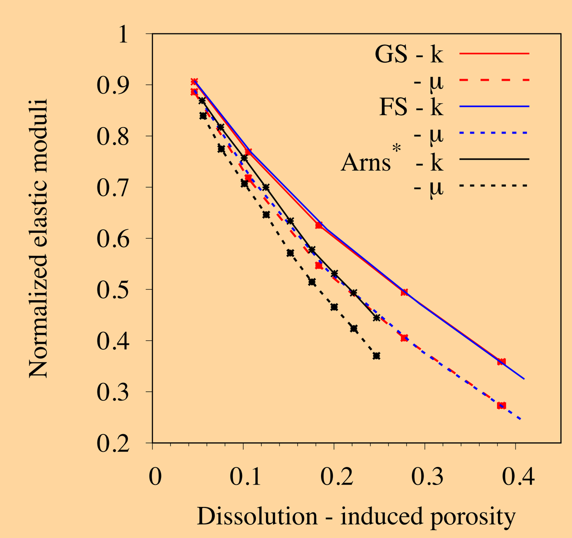
$P(\cdot)$ – computed elastic moduli

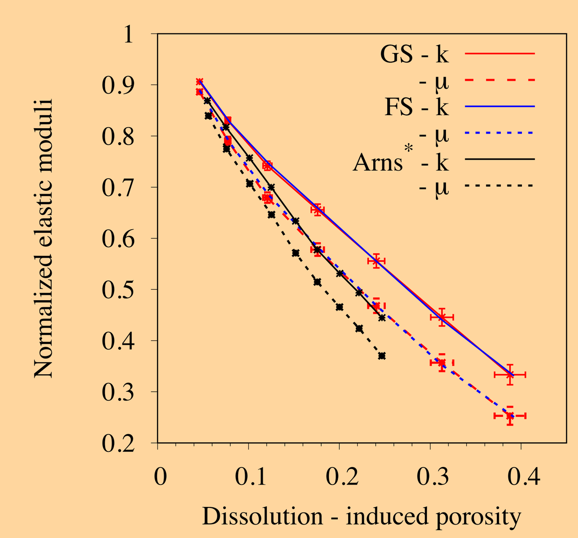
M – resolution

P_0 – searched value



[Roberts and Garboczi, 2002]





* Arns et al. 2002

Permeability - Elasticity Coupling

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

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

K – permeability

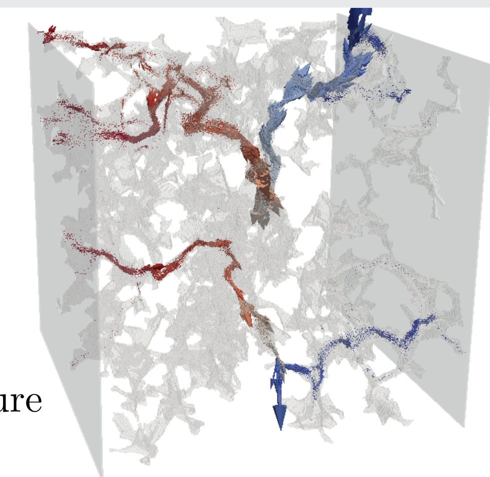
μ – dyn. viscosity

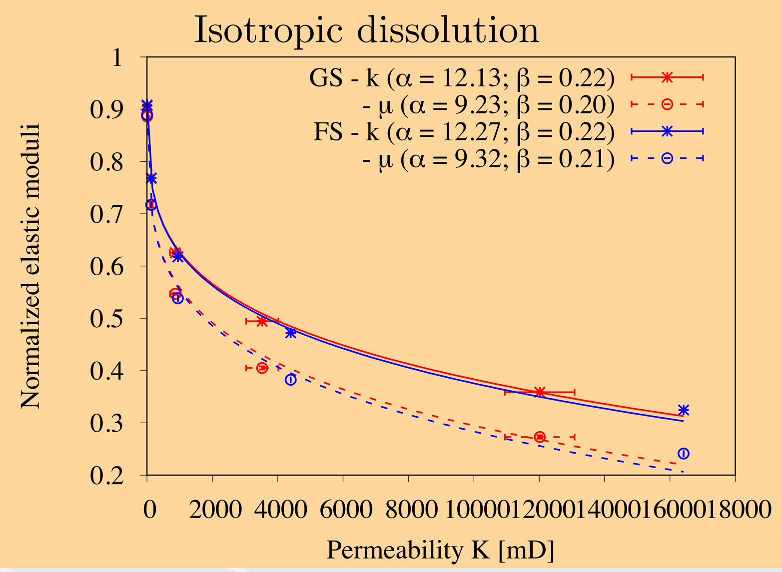
Q – flux

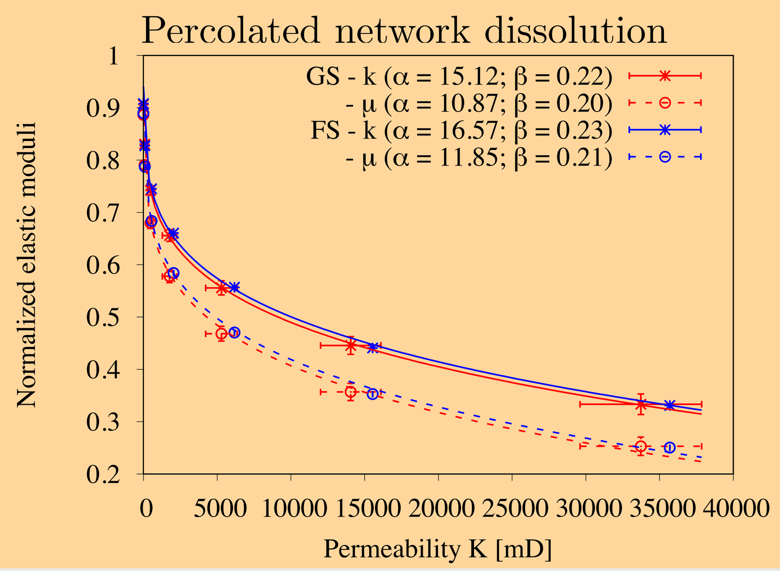
A – surface area

L – sample length

Δp – grad. of pressure







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