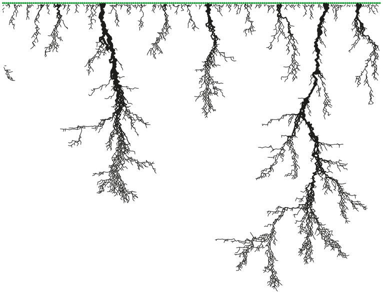
network models of dissolution and precipitation of porous media



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INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

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EUROPEAN REGIONAL DEVELOPMENT FUND

Chemical erosion

- chemical transformation of porous media
- dissolution process is of fundamental importance in a variety of geological systems
- an example of chemical reaction

$$CaCO_3 + 2H^+ \rightarrow CO_2 + H_2O + Ca^{2+}$$

Figure: Karst caves in Luary.

Engineering applications

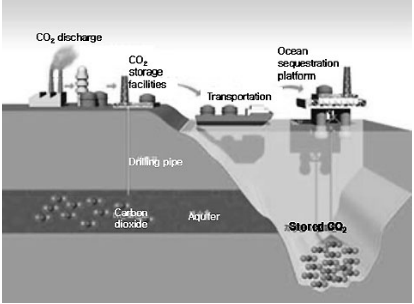


Figure: The process of injecting carbon dioxide into the earth.

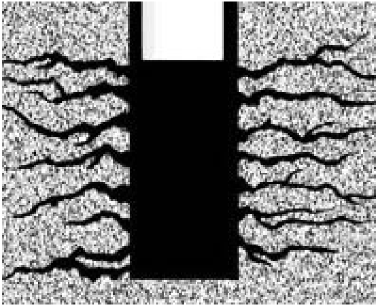


Figure: Stimulation of petroleum reservoirs.

Network model

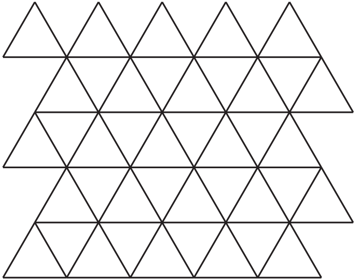


Figure: Triangular lattice with regular nodes.

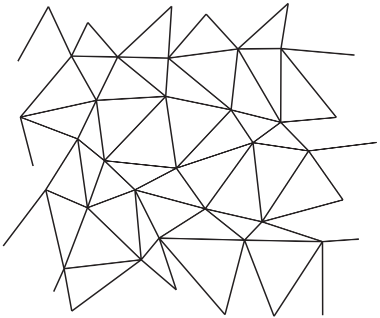


Figure: Triangular lattice with random nodes.

Network model

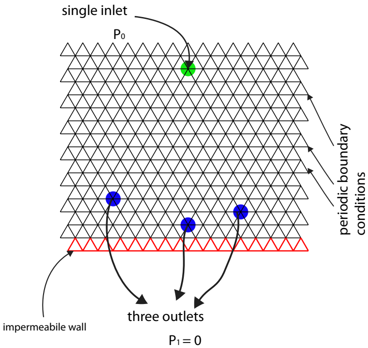


Figure: Scheme of a network with punctual inlet and outlets.

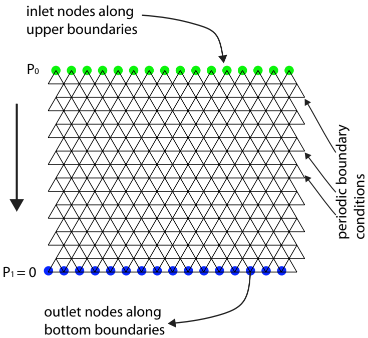
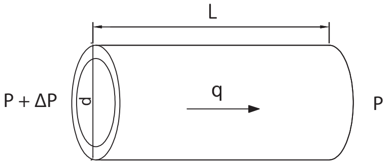


Figure: Scheme of a network with line inlets and outlets.

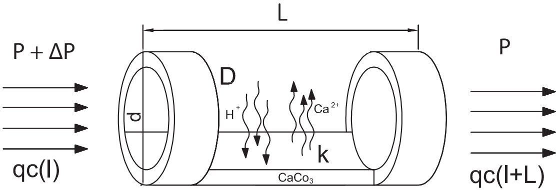
Theoretical Model



$$q = -\Delta P \frac{\pi d^4}{128 \mu L} \quad (1)$$

The fluid flow is proportional to the pressure drop. Adding contiguity condition we get Ohm's law and the network of pores can be regarded as resistor lattice that evolves in time.

Theoretical Model



$$\Delta d = \frac{\Delta t}{Da_{eff}(1+G)}(1 - e^{-Da_{eff}}) \qquad C(l) = C_0 e^{-Da_{eff}\frac{l}{L}} \qquad (2)$$

$$Da_{eff} = \frac{\pi d k_{eff} L}{q} \qquad G = \frac{kd}{D} \qquad (3)$$

Implementation of the model

- Pressure in each node and flow through each tube are obtained using MUltifrontal Massively Parallel Solver (MUMPS).

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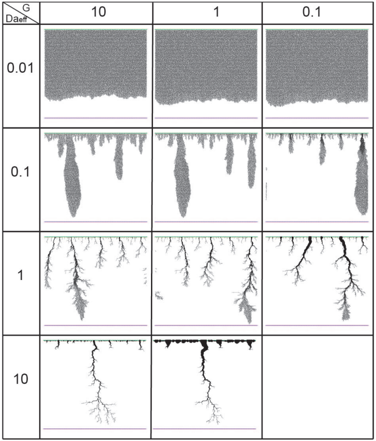
- Pressure in each node and flow through each tube are obtained using MUltifrontal Massively Parallel Solver (MUMPS).
- The concentration field in each pore, starting from the inlet ones, is calculated.
- The diameters of the pores are updated.
- Additionally the merging of neighbouring pores is carried out.

Variety of dissolution patterns



Competition of the wormholes

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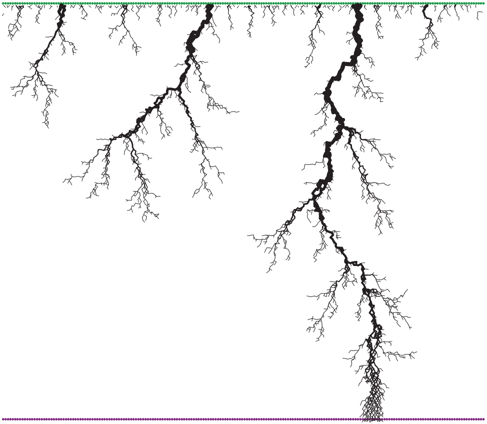

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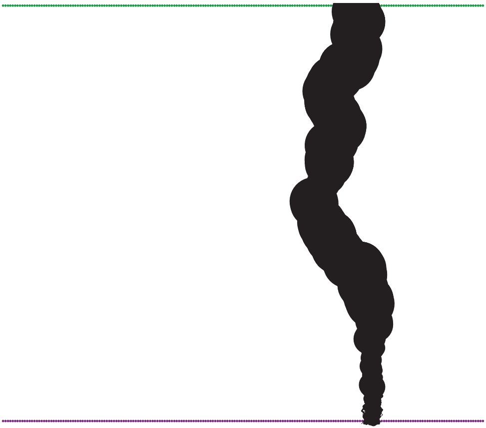
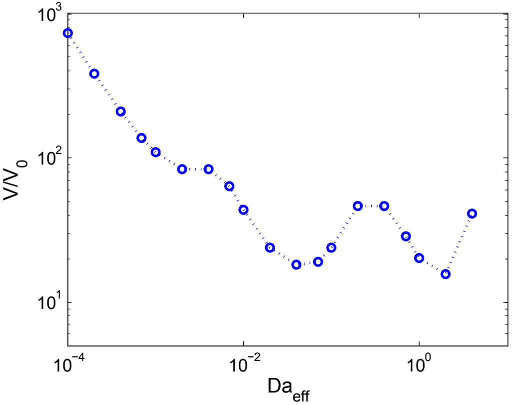


Pore volume to breakthrough



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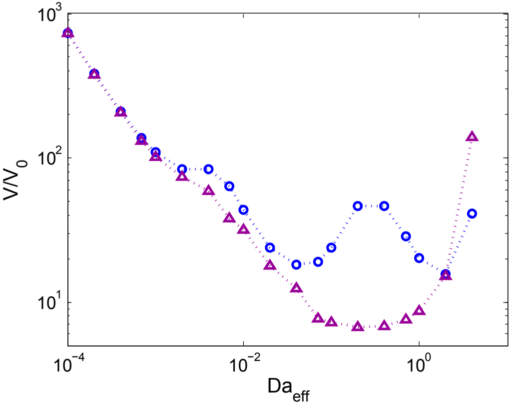

Two reaction types - dissolution and precipitation

$$SiO_2 + 6HF \rightarrow SiF_6^{2-} + 2H_2O + 2H_2^{+} \quad (4)$$

$$2Na^{+} + SiF_6^{2-} \rightarrow Na_2SiF_6, \quad (5)$$

Precipitation depending on K and Γ

$$K = \frac{k_{wy}}{k_{roz}}$$

$$\Gamma = \frac{\rho_{roz}}{\rho_{wy}}$$

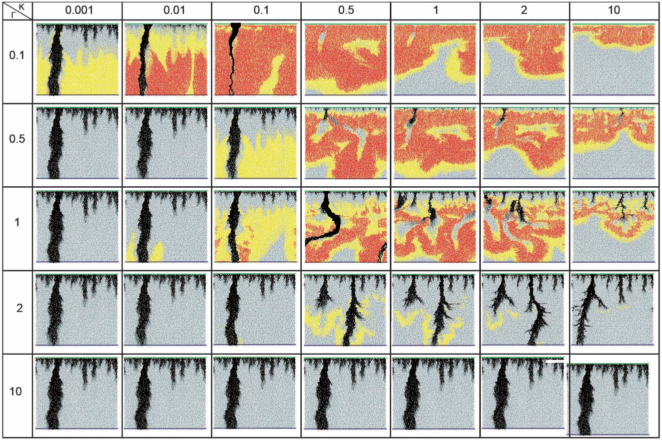

Figure: Dissolution and precipitation with fixed flow.

Time to breakthrough including precipitation.

$K \backslash \Gamma$	0.1	0.5	1	2	10
0.001	3.85×10^5	1.75×10^5	$2. \times 10^5$	2.25×10^5	2.57×10^5
0.002	2.31×10^6	1.45×10^5	1.75×10^5	2.08×10^5	2.51×10^5
0.005	–	2.83×10^5	1.48×10^5	1.87×10^5	2.47×10^5
0.01	–	–	2.09×10^5	1.72×10^5	2.37×10^5
0.02	–	–	–	1.54×10^5	2.42×10^5
0.05	–	–	–	–	3.64×10^5
0.1	–	–	–	–	2.71×10^5

Table: Time to breakthrough for different Γ and K in simulation with fixed Q; ($Da_{eff} = 1$ i $G = 1$). Time in simulation without precipitation is equal to $T_0 = 2.69 \times 10^5$.

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Precipitation speeding up the dissolution time

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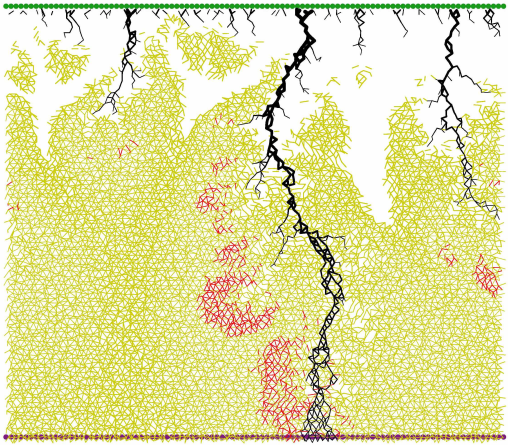
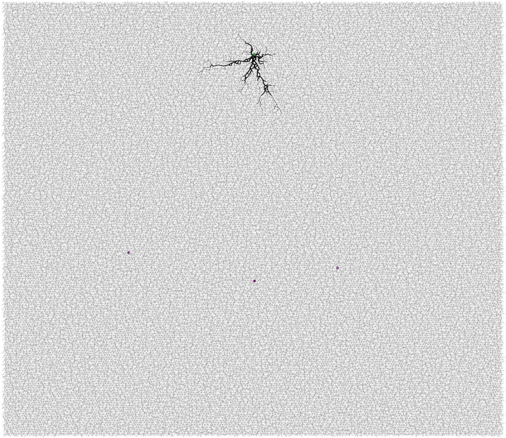


Competition between dissolution and precipitation



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thank you for your attention