Characterization of type I source rock by pore-scale simulations

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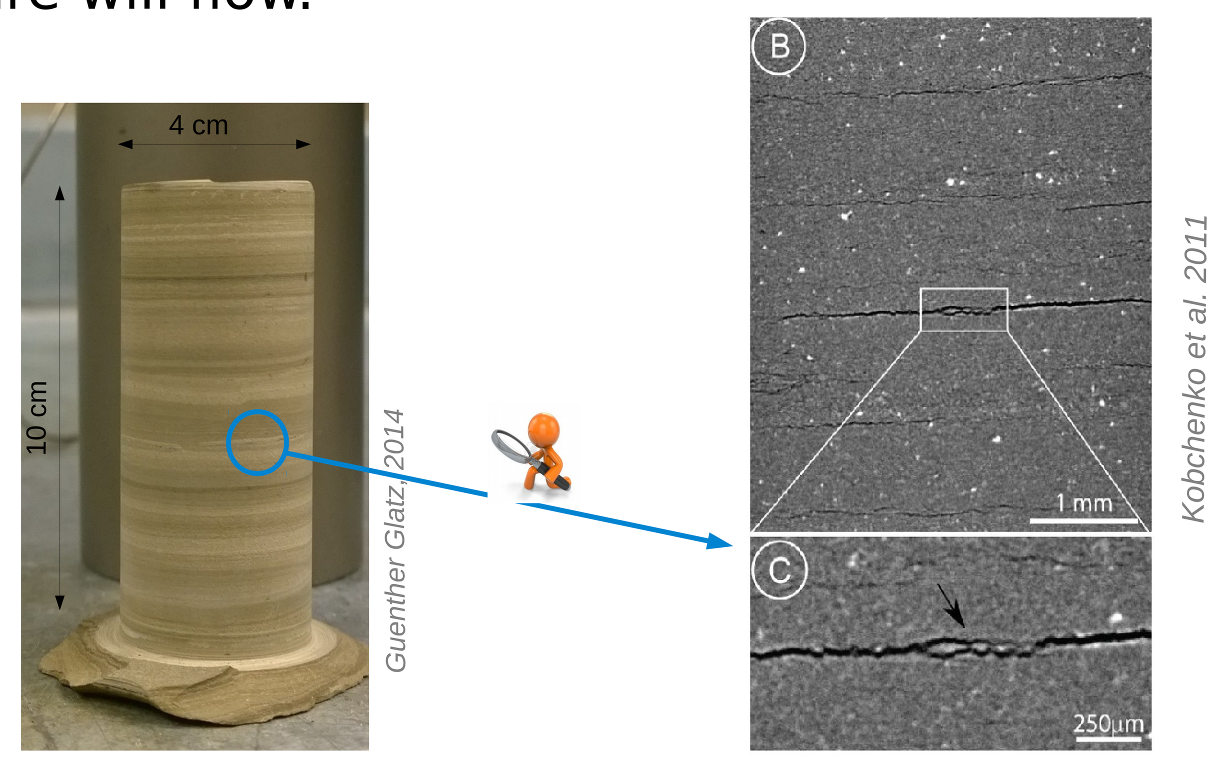
Introduction

Deposits of oil shale occur around the world and the estimates range from 4.8 to 5 trillion barrels of oil in place. Oil shale is a compact (very low permeability, very low porosity), laminated rock containing an organic matter called kerogen. In-situ upgrading process uses heat to decompose the solid kerogen through a series of chemical reactions, the pyrolysis, into liquid and gas hydrocarbons. During the heat-up stage some micro-cracks will propagate wherein the mixture will flow.

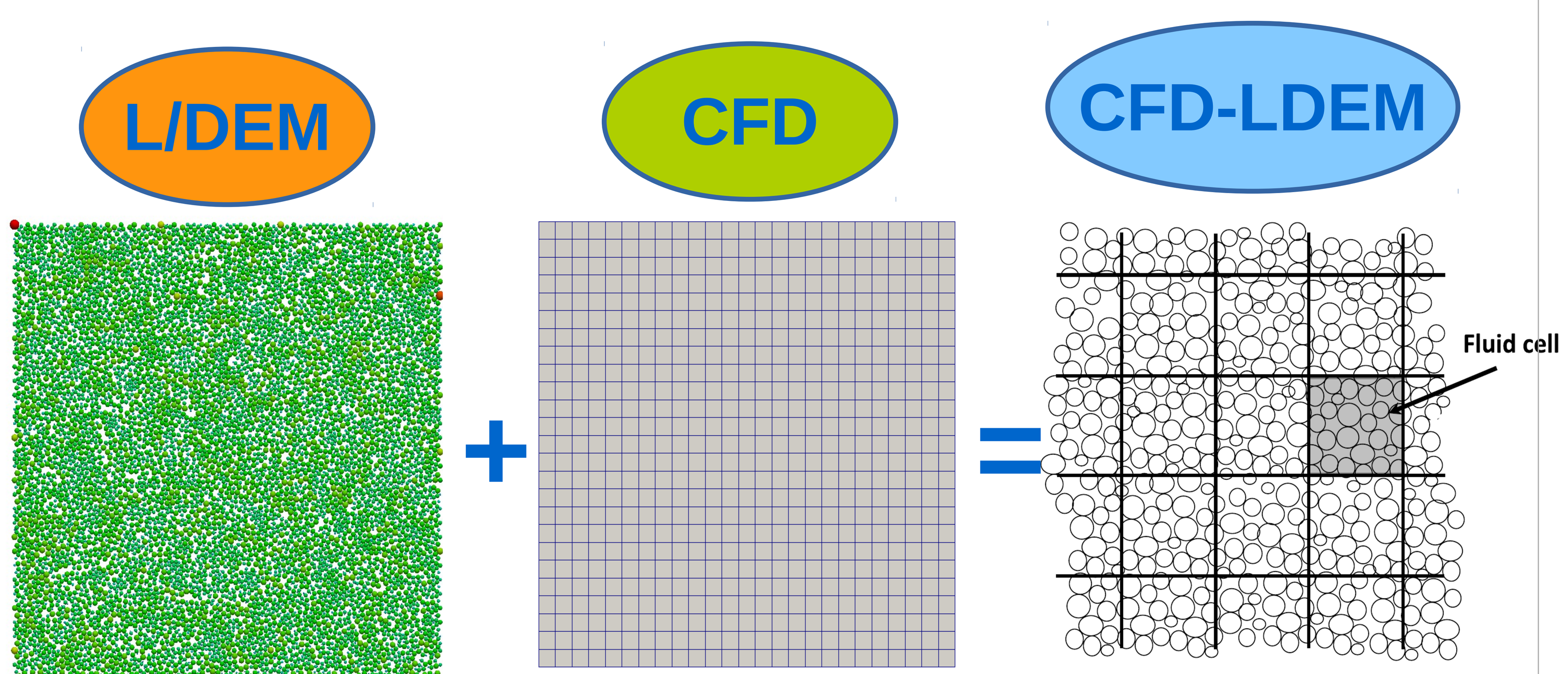


There are different origins to this creation of porosity:

- At high temperature, the kerogen starts to transform into volatile matter (pyrolysis),
- Fracturing due to the temperature induces brittle behavior of the solid,
- Fracturing due to the excessive pore-pressure.

We want to represent explicitly the crack propagation and the mixture flowing through the generated micro-fractures.

Modeling strategy



(mesh free) Newton's law

(cartesian grid) Locally Averaged Navier-Stokes equations

Four-way coupling

CFD model for oil shale pyrolysis

The model is based on a Darcy-Brinkman formulation in a fixed grid that allows the use of the same formulation both in the fractured area and the solid kerogen.

$$\frac{\partial \varepsilon_k \rho_k}{\partial t} = -\dot{m},$$

$$\frac{\partial \varepsilon_f \rho_f}{\partial t} + \nabla.\left(\rho_f \mathbf{u}_f\right) = \dot{m},$$

$$0 = -\nabla p_f + \mu_f^* \nabla^2 \mathbf{u}_f - \mu_f k^{-1} \mathbf{u}_f$$

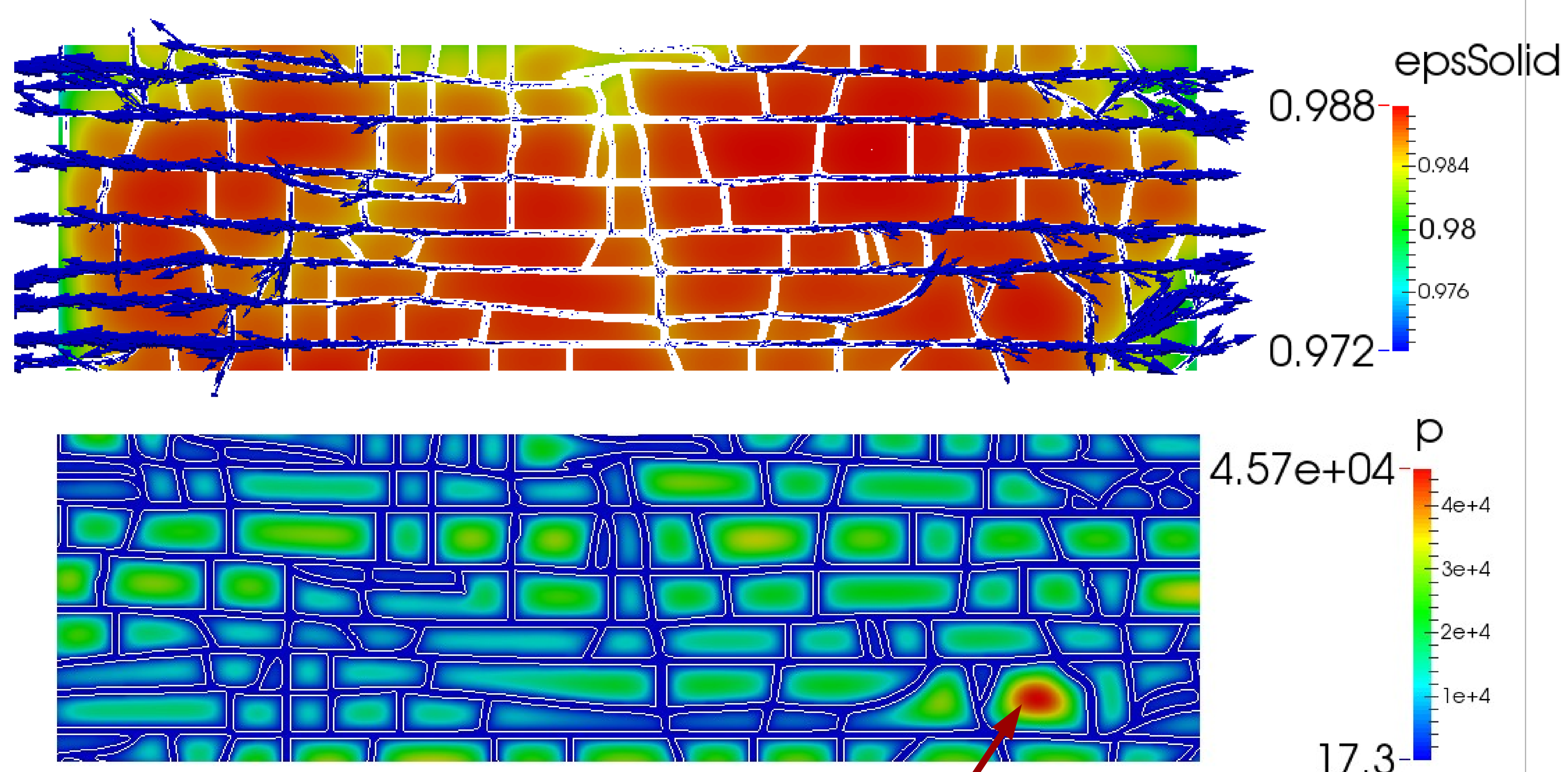
$$\rho C_p \frac{\partial T}{\partial t} + \rho_f C_{p_f} \mathbf{u}_f . \nabla T = \nabla.\left(\lambda \nabla T\right) - \triangle H_{pyr} \frac{\partial \rho_k \varepsilon_k}{\partial t}$$

$$\dot{m} = A \exp\left(-\frac{E_a}{RT}\right) \varepsilon_k \rho_k \qquad \rho_f = \frac{M_f p_f}{RT} \qquad k^{-1} = k_0^{-1} \frac{(1-\varepsilon_f)^3}{\varepsilon_f^2}$$

Pyrolysis in existing fracture network

Simulation of 1mm x 0.25mm fractured oil shales when homogeneously heat up at 570 K during 8 min.

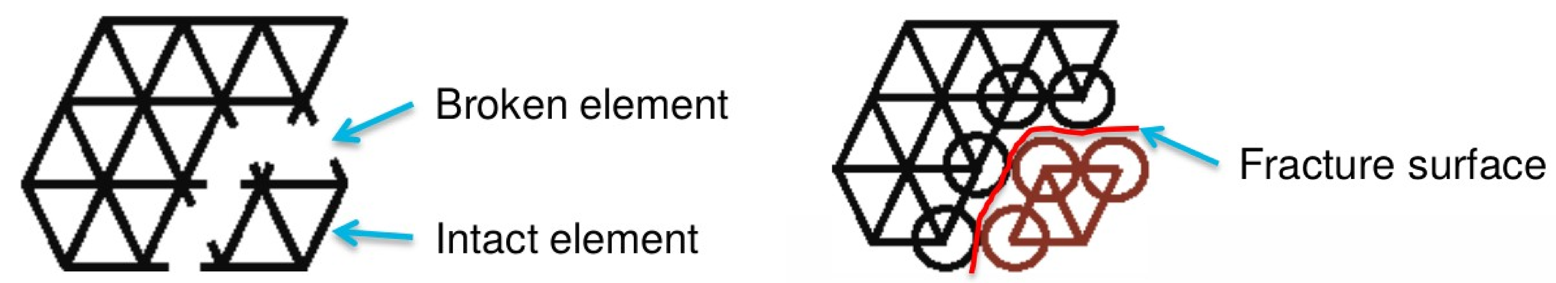
ρ_k	C_{p_k}	C_{p_f}	μ_f	λ_f	λ_k	M_f	E_a	A	ΔH_{pyr}	k_0
(kg/m^3)	(J/kg/K)	(J/kg/K)	(Pa.s)	(W/m/K)	(W/m/K)	(kg/kmol)	(J/kmol)	(s^{-1})	(J/kg)	(m^2)
1500	2700	1800	10^{-5}	0.07	1	20	160×10^6	3×10^{13}	375×10^3	10^{-13}

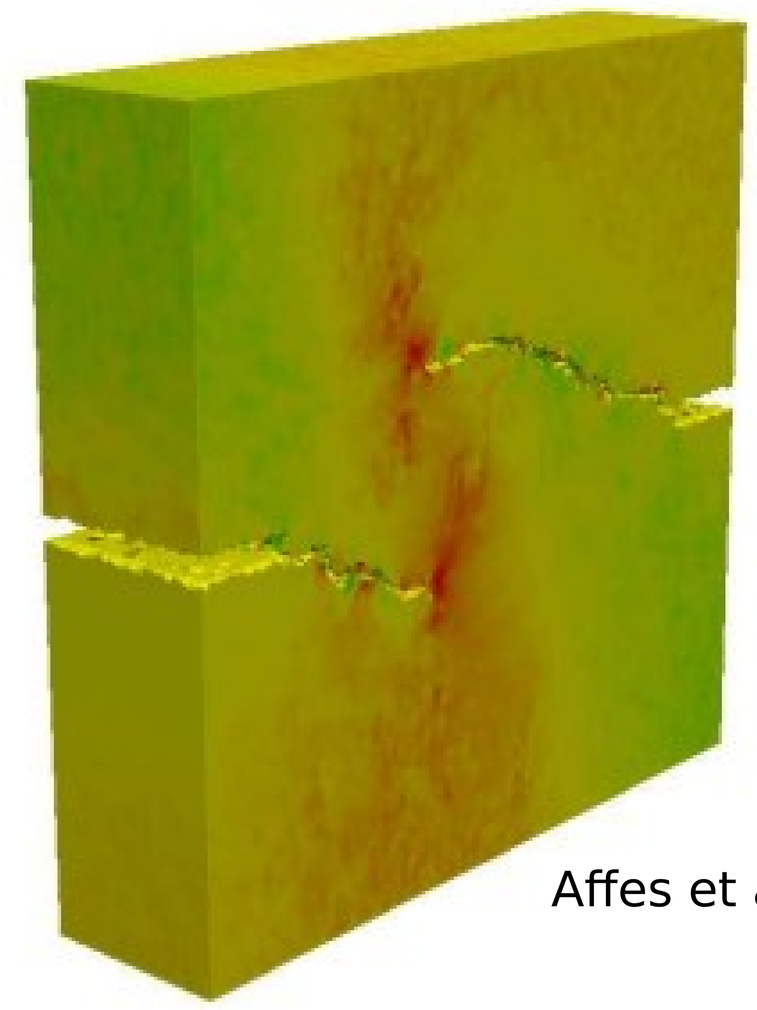


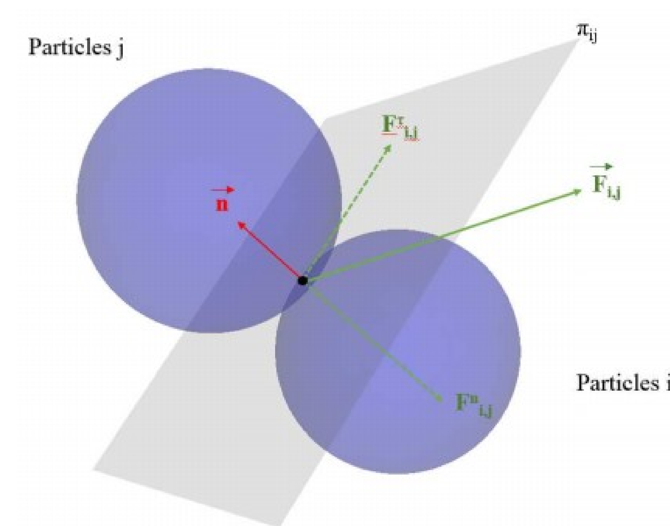
Large excessive pressure in larger grains (related to the distance to the nearest drainage, *Kobchenko, 2013*) indicates that the grain will crack.

Lattice-Discrete Element Method

In this method, the solid phase is represented by a lattice of springs. When a spring breaks, it is replaced by two sphere elements in contact with each other.







Affes et al. (2015)

Next steps

- Couple fluid flow and rock mechanics,
- Comparison with ongoing experiments,
- Upscale the results to a Darcy's scale model.

References

Kobchenko et al., *4D imaging of fracturing in organic-rich shales during heating*, Journal of Geophysical Research: Solid Earth (2011)

Kobchenko et al., *Drainage fracture networks in elastic solids with internal fluid generation*, Europhysics Letters (2013)

Affes et al., *A lattice-discrete element method for modeling of thermo-mechanical processes in geological formations*, Int. J. Numer. Anal. Meth. Geomech (under review)

Acknowledgements

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