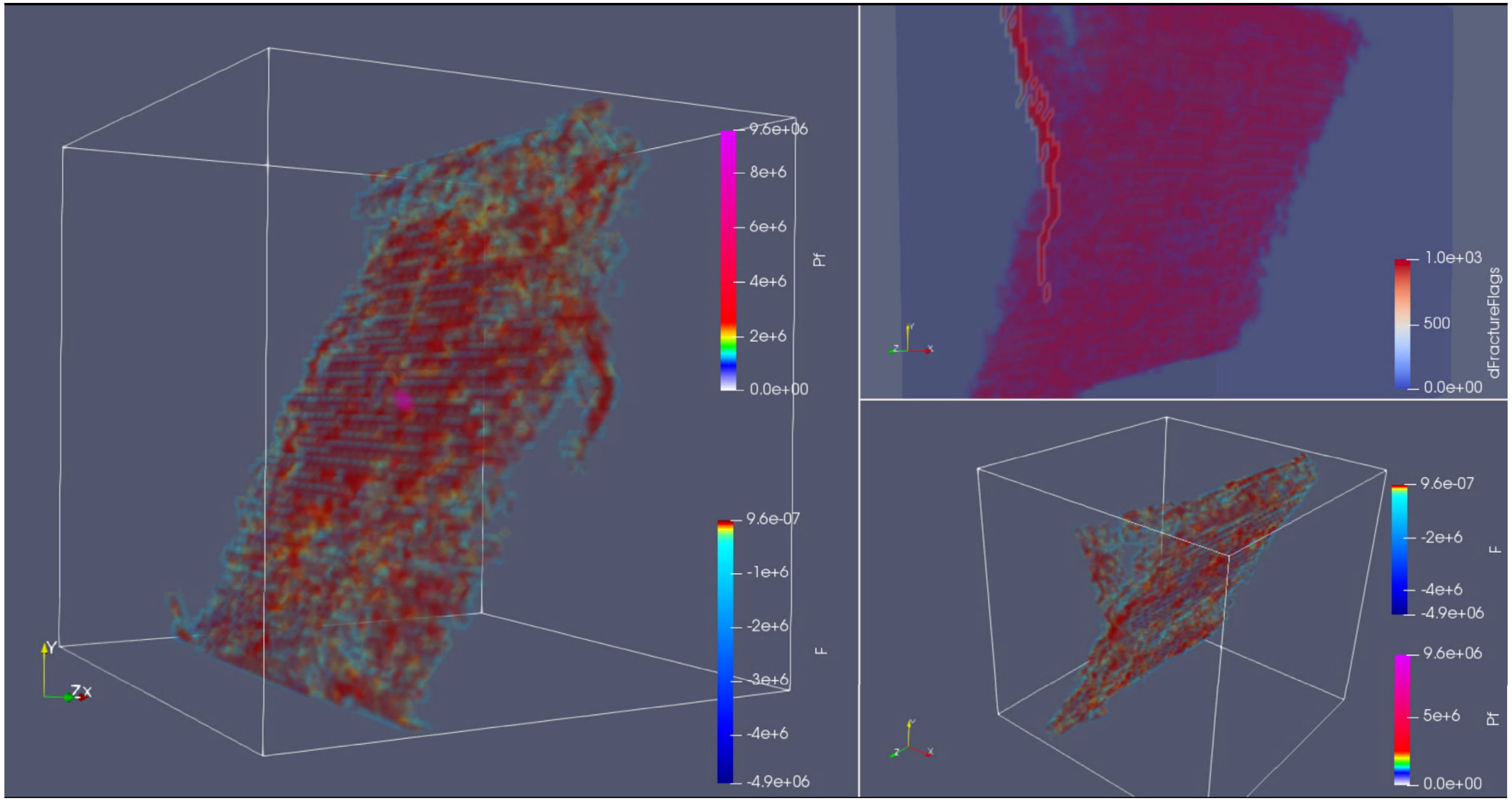
Using a THMC Simulator to Examine the Effects of Porosity Reduction in Geothermal Reservoirs

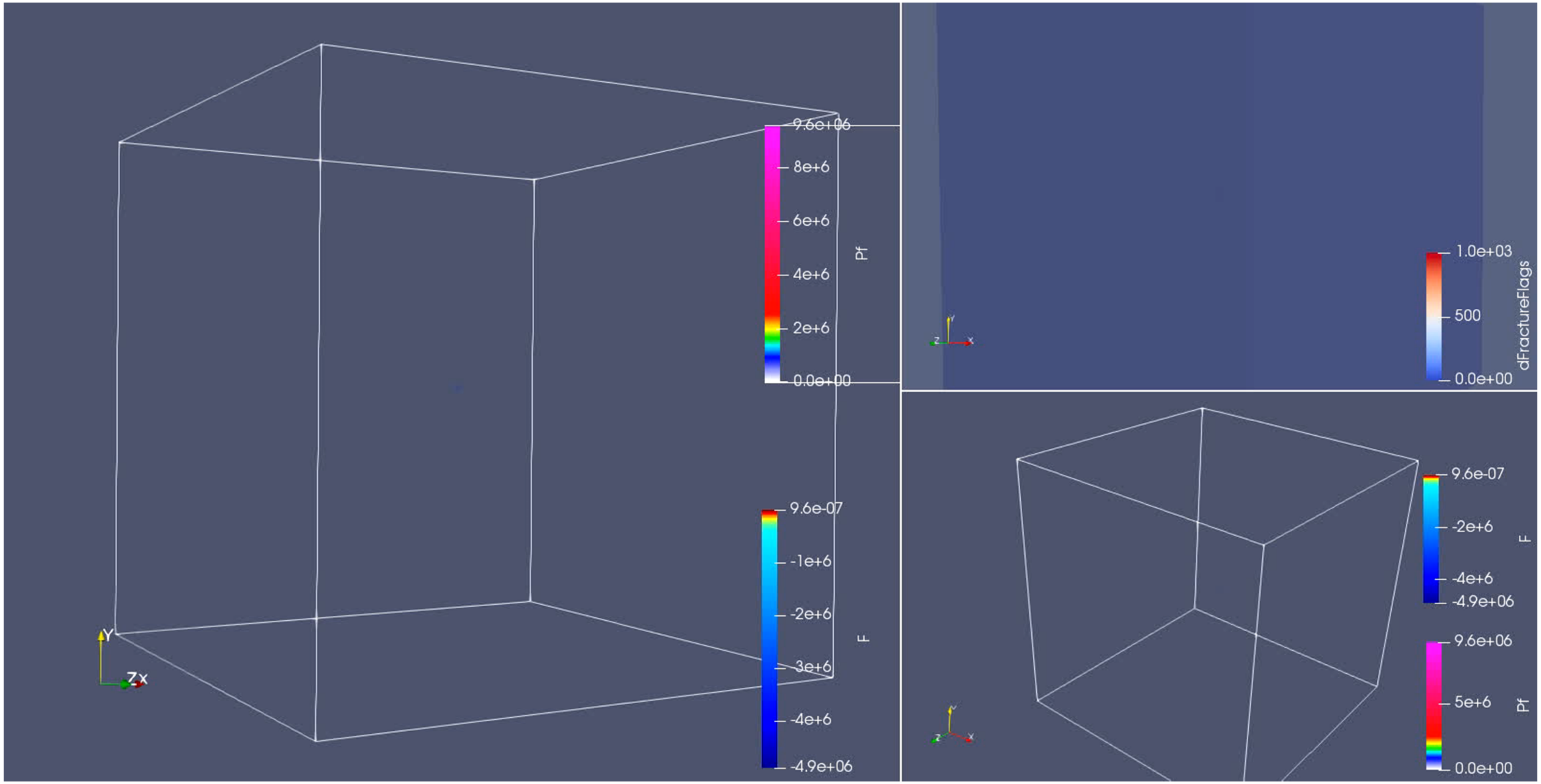
Batoul Gisler, Boris Galvàn, Reza Sohrabi, Stephen Miller



EFRACK3D

- EFRACK 3D is a fully coupled Thermo-Hydro-Mechanical and Chemical (Non-reactive flow), multi-GPU simulator.
- Yield function and the fluid pressure are shown with a resolution of 64x64x64.
- Conceptual model :
    - It is a rock cube under triaxial compression of 10 MPa and with an initial temperature of 120°C.
    - Maximum fluid injection pressure of 9.55MPa and a temperature of 60°C.
- Results:
    - At the vicinity of the injection point localized events are popping and the evolution of the fracture network is shown in 3D.
    - We can visualize the massive failure of the domain mainly at the edges.

EFRACK3D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Pf
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-3e+6
-4e+6
-4.9e+06
F
1.0e+03
500
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dFractureFlags
9.6e-07
-2e+6
-4e+6
-4.9e+06
F
9.6e+06
5e+6
0.0e+00
Pf

CONTENT

- EFRACK3D
- Motivation
- Why Quartz?
- The reactive flow model:
  - Approach
  - Conceptual model
  - Mathematical model
- Outlooks

EFRACK3D: THERMO-HYDRO-MECHANICAL-CHEMICAL (NON-REACTIVE FLOW) MULTI-GPU SIMULATOR

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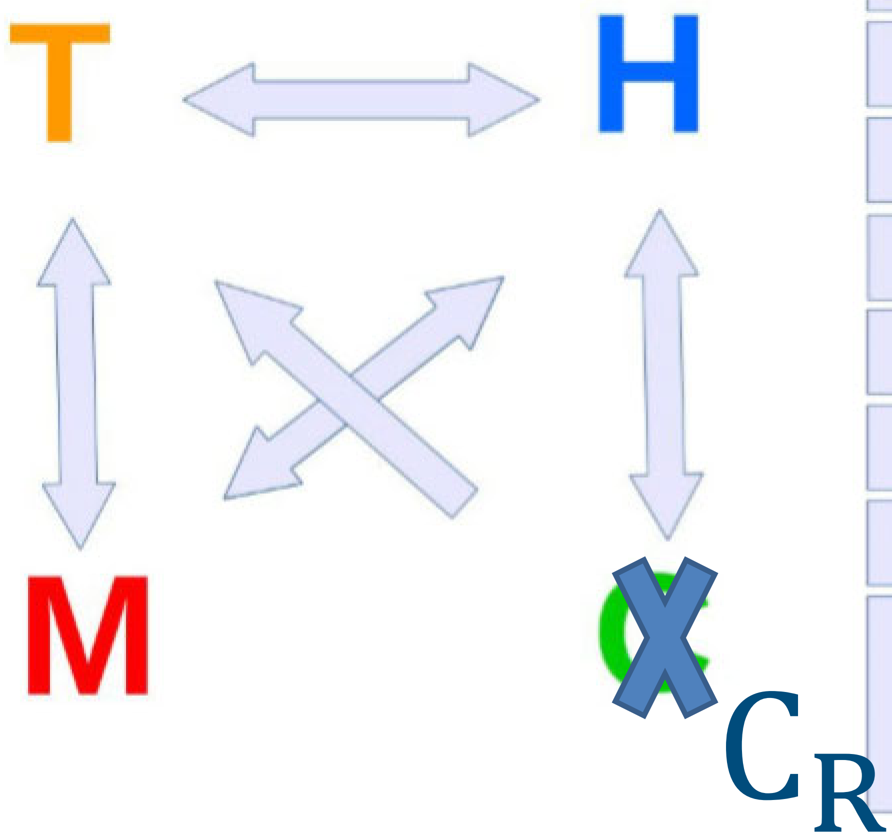


M → H	* Permeability increment when fracturing * Mechanical over-pressurization * Porosity dependent on volumetric strain
M → T	* Shear heating
H → M	* Effective stresses * Gassmann equations
H → T	* Darcy velocity
H → C	* Darcy velocity
T → M	* Thermal stresses
T → H	* Thermal pressurization
C → T	* Heat capacity dependent on P,T,C
C → H	* Fluid density dependent on P,T,C * Fluid compressibility dependent on P,T,C * Fluid expansion coefficient dependent on P,T,C * Fluid viscosity dependent on P,T,C

MOTIVATION

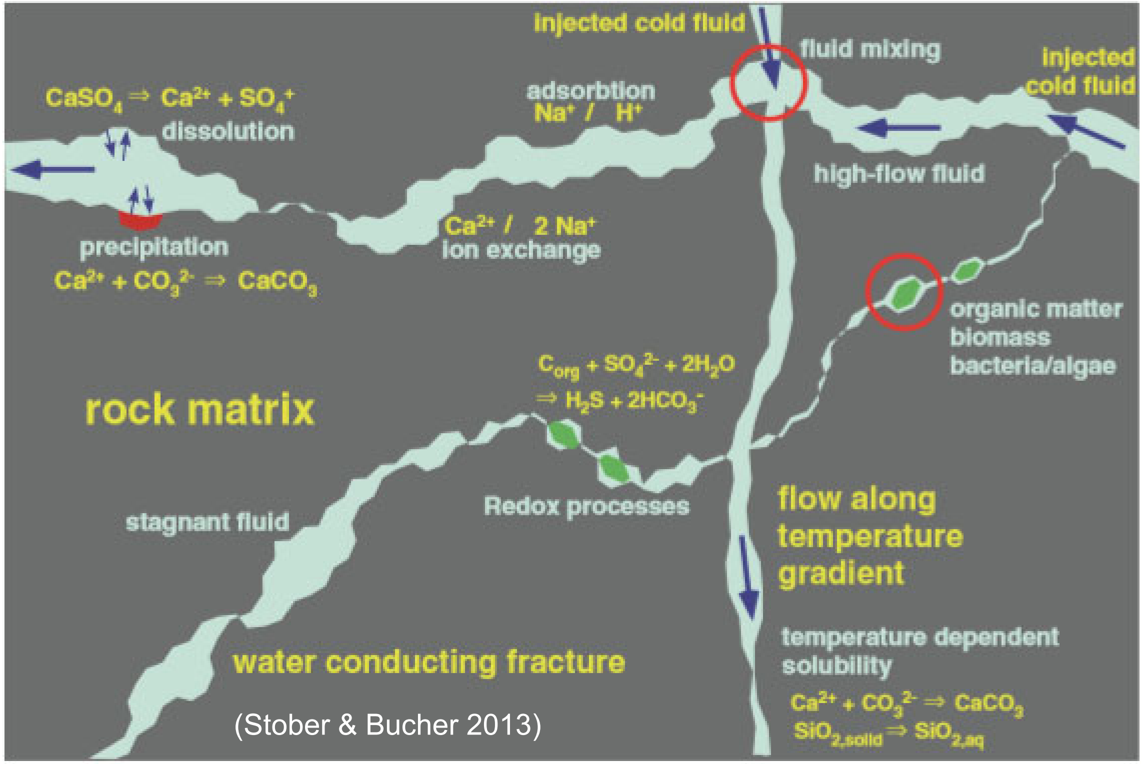
- **Porosity changes** due to quartz precipitation and dissolution affects the general response of the host rock.

- **Scaling** affects the machinery and hinders the productivity of the geothermal energy project.

- **Permeability decrease** due to quartz/calcite precipitation has been proposed to affect the temporal decay of aftershocks following large earthquakes.

Sustainable reservoir development requires a combined analysis of the thermo-hydro-mechanical and chemical processes.

WHY QUARTZ?

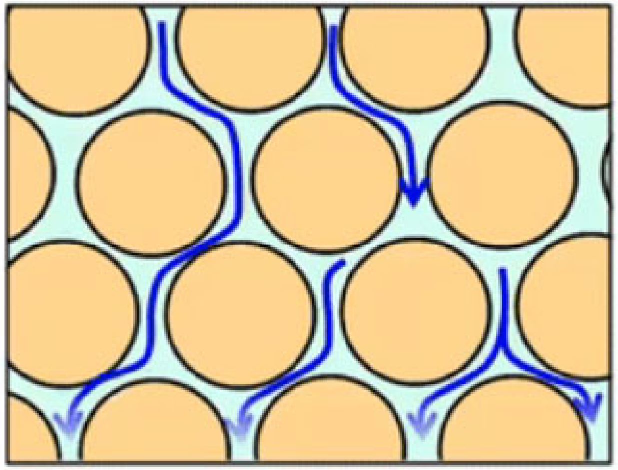


(Stober & Bucher 2013)

- Energy production requires deep geothermal reservoir exploration.
- Geology of deep geothermal reservoirs in Switzerland is mostly Granite.
- Aftershock theory occurs at larger depths.

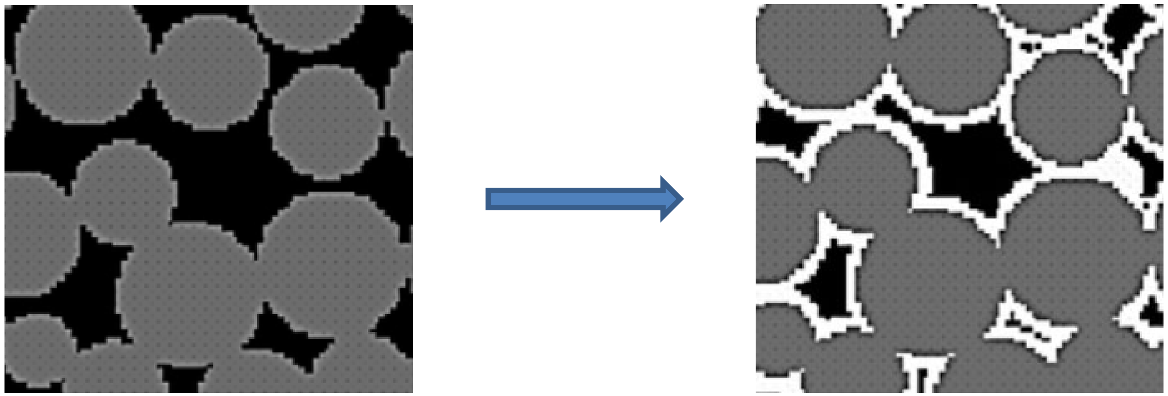
CONCEPTUAL MODEL

The geometry of the model assumes a porous medium (block) in which chemical reactions occur between the pore fluid and the rock matrix.



$$H_4SiO_{4(aq)}=SiO_{2(s)}+2H_2O_{(l)}$$

The reactive flow model assumes a coupling between heat and fluid mass transport.



APPROACH

The combination of chemical and mechanical porosity changes is not a trivial problem.

Proposed solution

- The term that describes the change in porosity and permeability due to chemical processes should be “integrable” with EFRACK 3D.
- To describe the change in porosity due to chemical reactions, we look at the change in diameter of the grain due to quartz precipitation and dissolution.
- Combine the change in porosity due to mechanics with the change in diameter due to chemical processes.

MATHEMATICAL MODEL

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Required Input

- Initial Conditions
- Boundary conditions
- Rock and fluid properties

Reactive flow model
System of equations

Desired Output

- Solute transport of the mineral
- New Porosity
- New Permeability

New contact surface area A

t=t+dt

MATHEMATICAL MODEL

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$$\frac{\partial C'}{\partial t} = D_m \nabla^2 C' + \vartheta \nabla C' - \frac{K}{\emptyset} C'$$

$$C' = c - c_{eq}$$

$$K = \frac{A}{M} k_{-}$$

Diffusion coefficient within the reservoir matrix

$$log c_{eq} = -\left(\frac{1107}{T}\right) - 0.025$$

$$log k_{-} = -0.707 - \frac{2589}{T}$$

MATHEMATICAL MODEL

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Mass conservation of silica is given by the Partial Differential Equation:

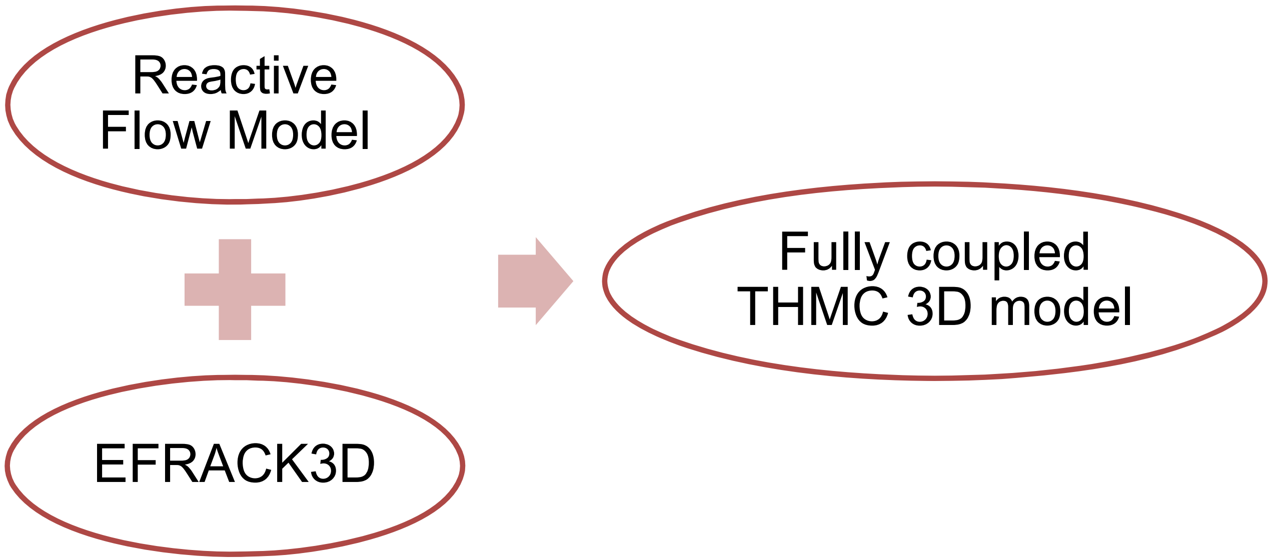
Flow rate

$$\frac{\partial(\emptyset C')}{\partial t} = -\nabla(uC') - \emptyset K(C')$$

Kozeny-Carman Equation for permeability:

$$k = cd^2 = \left(\frac{\emptyset^3}{180(1-\emptyset)^2}\right) d^2$$

OUTLOOKS



- Estimate **porosity** and **permeability** evolution in the reservoir rock due to THMC processes.
- Visualize possible **localized cracking** due to pore pressure developement and better understand fluid driven aftershocks.
- Add some variety by introducing a **multi-GPU technology**.

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Reactive Flow Model for Porosity Reduction by Quartz Dissolution and Precipitation

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Introduction

Quartz dissolution and precipitation is an important pore reducing process in geothermal reservoirs. It also causes scaling, which affects the machinery and hinders the productivity of the geothermal energy project. Furthermore, permeability decrease due to quartz deposition has been proposed as an important factor in the temporal decay of aftershocks. In this work we present a reactive flow model to study the evolution of porosity, permeability and solute transport of the system. The geometry of the model assumes a porous medium block in which chemical reactions occur between the pore fluid and the rock matrix. The model assumes a coupling between heat and fluid mass transport. The Center for Hydrogeology and Geothermics has recently developed **"Efrack3D"**, a fully coupled 3D Thermo-Hydro-Mechanical (THM) model. We aim to ultimately integrate the reactive flow model with the THM model. Economic reservoir development requires a combined analysis of the thermo-hydro-mechanical and chemical processes.

Approach and model geometry

Quartz dissolution and precipitation is a surface controlled reaction, and is therefore highly temperature dependent. The solubility of silica increases rapidly with temperature, to almost double between 80°C and 110°C [1]. Fig.1 represents a road map of the **reactive flow** model. First, all temperature dependent parameters are calculated and initial and boundary conditions are defined. The REV of the system is a block composed of spherical shaped grains with an initial porosity. The change in contact area between the grains due to quartz precipitation and dissolution is calculated based on [2]. The solute transport equation includes both diffusion and advection terms, and is solved with finite difference method. Once the concentration is calculated, the porosity evolution is computed via the mass conservation equation. The new porosity is used to recalculate the contact surface area at each time step. Finally, the permeability is estimated as a function of time and space, allowing us to predict pore pressure evolution in the reservoir. In the beginning, to simplify the problem we assume no compaction of the grains, nevertheless, vertical stress and consolidation are controlling factors in the variation of the surface contact area.

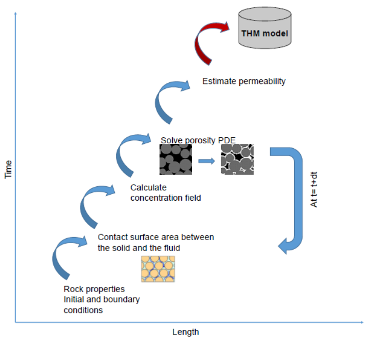

Figure 1: Road map for the reactive flow model as a function of time and length scales.

Mathematical model

$$H_4SiO_{4(aq)} = SiO_{2(s)} + 2H_2O_{(l)}$$

The precipitation rate constant k_- and the equilibrium quartz concentration c_{eq} are given by [3]:

$$log k_- = -0.707 - \frac{2589}{T} \quad \text{Eq. 1}$$

$$log c_{eq} = -\left(\frac{1107}{T}\right) - 0.025 \quad \text{Eq. 2}$$

Solute transport for quartz precipitation and dissolution in the rock matrix is described by the linear reaction equation:

$$\frac{\partial C'}{\partial t} = D_m \nabla^2 C' - \frac{K}{\emptyset} C' \quad \text{Eq. 3}$$

We solve Eq.3 using total variation diminishing method, where $C' = c - c_{eq}$.The apparent precipitation rate constant K is given by:

$$K = \frac{A}{M} k_- \quad \text{Eq. 4}$$

Where A is the interfacial area between the solid and the fluid of mass M [2]. Mass conservation of silica is governed by:

$$\frac{\partial(\emptyset c)}{\partial t} + \frac{\partial(uc)}{\partial x} = -\emptyset K(c - c_{eq}) \quad \text{Eq. 5}$$

Assuming a constant flow rate, Eq. 5 represents porosity evolution and is solved using finite difference scheme.

Finally, permeability is estimated using the Cozeny-Carman Equation.

Outlooks

We ultimately aim to investigate the consequences of quartz dissolution and precipitation on the mechanical response of the rock matrix. It is essential for sustainable wellbore productivity and development. The porosity and permeability evolution terms may be integrated to the Efrack3D to visualize pore pressure development and analyze the geomechanics. Furthermore, this may allow us to visualize possible localized cracking due to pore pressure developement and better understand fluid driven aftershocks, as it has been stated that repeated fracturing events followed by crack healing are in connection with earthquakes [4].

References

[1] Giles, M.R., Indrelid, S.L., Beynon, G.V., Amthor, J. (2000). The origin of large-scale quartz cementation: evidence from large data sets and coupled heat-fluid mass transport modelling. Spec. Publs int. Ass. Sediment, No. 29, pp. 21-38.

[2] Canals, M. & Meunier, J.D. (1995). A Model for porosity reduction in quartzite reservoirs by quartz cementation. Geochimica et Cosmochimica Acta, Vol. 59, No. 4, pp. 699-709.

[3] Rimstidt, J.D. (2013). Geochemical Rate Models: An Introduction to Geochemical Kinetics.

[4] Walder, J. & Nur, A. (1984). Porosity reduction and crustal pore pressure development. Journal of geophysical research, Vol. 89, No. B13, pp. 11,539-11,548.

Questions?

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References:

[1] Giles, M.R., Indrelid, S.L., Beynon, G.V., Amthor, J. (2000). The origin of large-scale quartz cementation: evidence from large data sets and coupled heat-fluid mass transport modelling. Spec. Publs int. Ass. Sediment, No. 29, pp. 21-38.

[2] Canals, M. & Meunier, J.D. (1995). A Model for porosity reduction in quartzite reservoirs by quartz cementation. Geochimica et Cosmochimica Acta, Vol. 59, No. 4, pp. 699-709.

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