A NOVEL METHOD FOR THC MODELS FOR AQUIFER THERMAL ENERGY STORAGE

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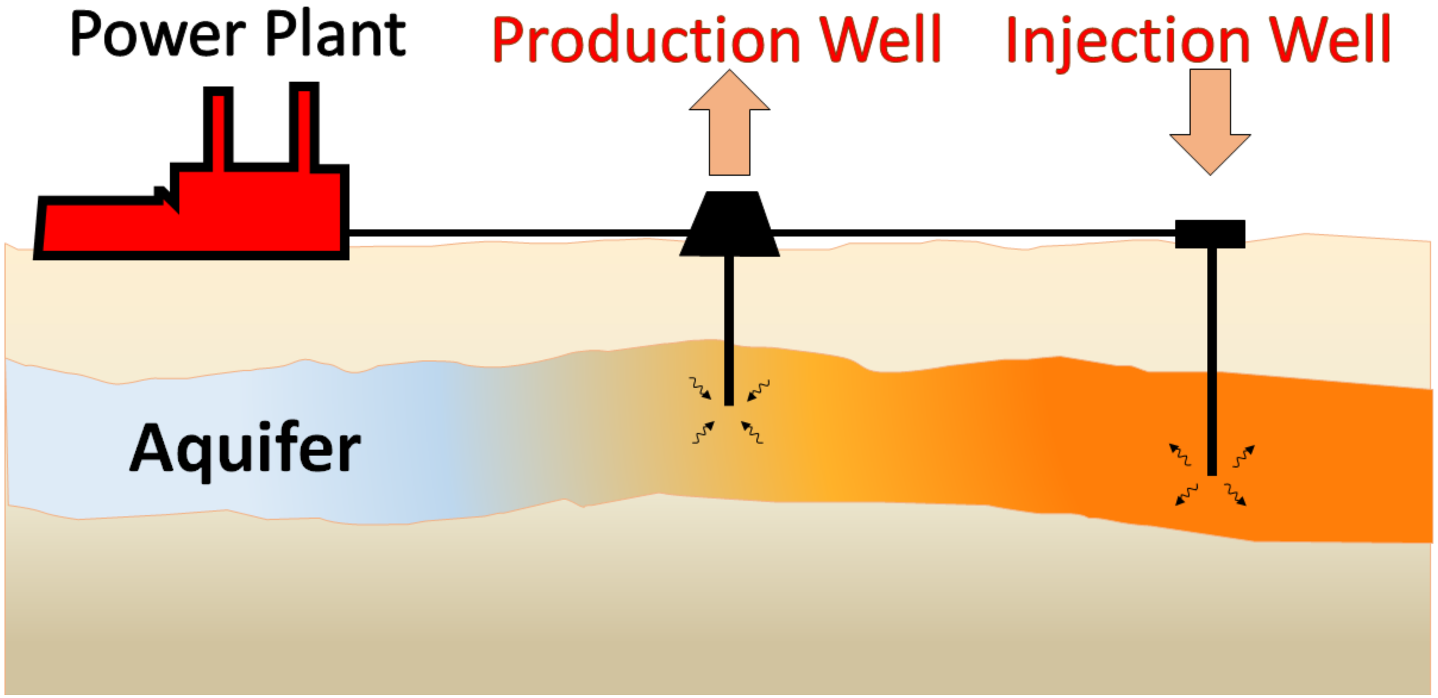
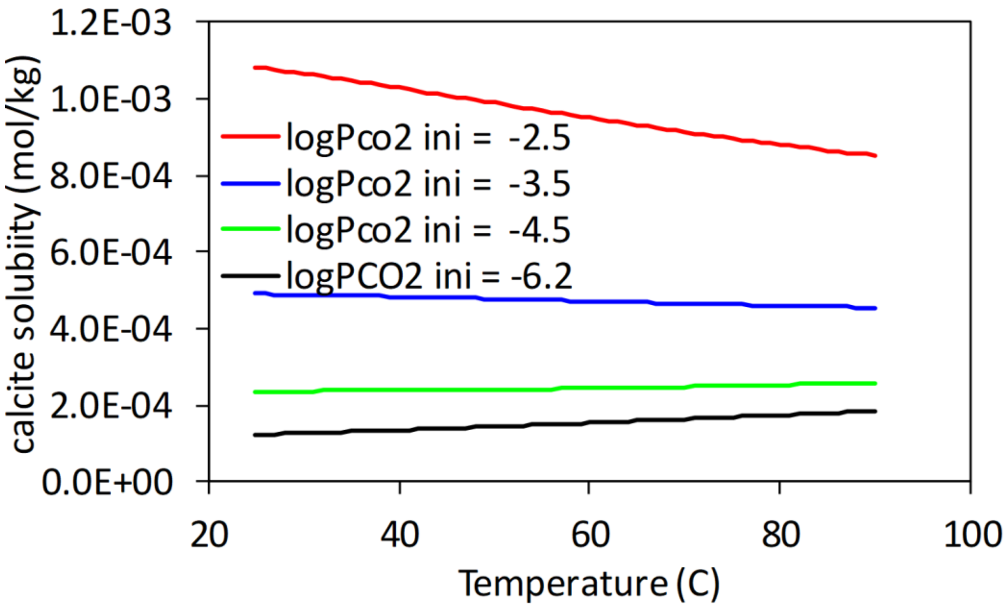
THERMAL IMPACT



Aquifer Thermal Energy Storage



Precipitation / Disolution

INDEX

1. **Methodology to obtain a (semi-)analytical solution**
   - Verification of numerical models
   - Understanding thermo-hydro-chemical phenomena
2. **Application to HT-ATES**
   - HEATSTORE benchmark inspired by Bern project

METHODOLOGY

- Rate of chemical reaction (De Simoni et al., 2007):

$$r = \underbrace{\frac{\partial^2 c}{\partial \alpha^2}}_{\text{Chemistry factor}} \underbrace{(\nabla \alpha)^T \phi \mathbf{D} \nabla \alpha}_{\text{Transport factor}}$$

- Reactive transport for calcite dissolution rate:

$$r_{calcite} = \phi \frac{\partial (c_{Ca} - c_{Mg})}{\partial t} + \mathbf{q} \cdot \nabla (c_{Ca} - c_{Mg}) - \nabla \cdot \left(\phi \mathbf{D} \nabla (c_{Ca} - c_{Mg}) \right)$$

- Heat equation for temperature (*T*):

$$\phi R C_a \frac{\partial T}{\partial t} + C_a \mathbf{q} \cdot \nabla T - \nabla \cdot (\lambda \nabla T) - \nabla \cdot \left(\phi C_a \mathbf{D}_{dis} \nabla T \right) = 0$$

- Heat equation substituted in reactive transport equations:

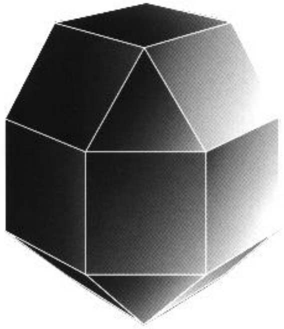
$$r_{calcite} = \underbrace{-\frac{\partial^2 (c_{Ca} - c_{Mg})}{\partial T^2} (\nabla T)^T \phi \mathbf{D} \nabla T}_{\text{Mixing}} + \underbrace{\frac{\partial (c_{Ca} - c_{Mg})}{\partial T} \left[(1 - R) \phi \frac{\partial T}{\partial t}\right.}_{\text{Heat retardation}} \underbrace{\left. - \nabla \cdot \left(\left(\phi D_{dif} - C_a^{-1} \lambda \right) \nabla T \right) \right]}_{\text{Heat conduction}}$$

De Simoni, M., Sanchez-Vila, X., Carrera, J., and Saaltink, M. W. (2007), A mixing ratios-based formulation for multicomponent reactive transport, *Water Resour. Res.*, 43, W07419, doi:10.1029/2006WR005256

ALGORITHM

1. Thermo-hydraulics

$$q \qquad T \qquad \nabla T \qquad \nabla^2 T \qquad \frac{\partial T}{\partial t}$$



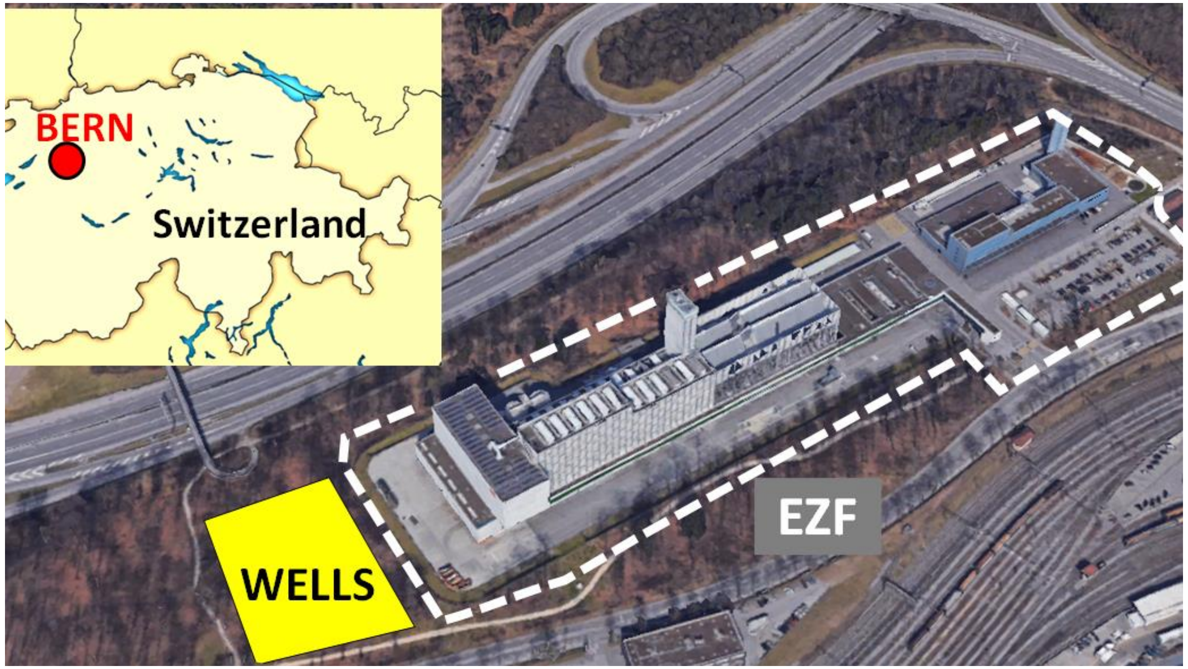
2. Chemistry: concentration – temperature

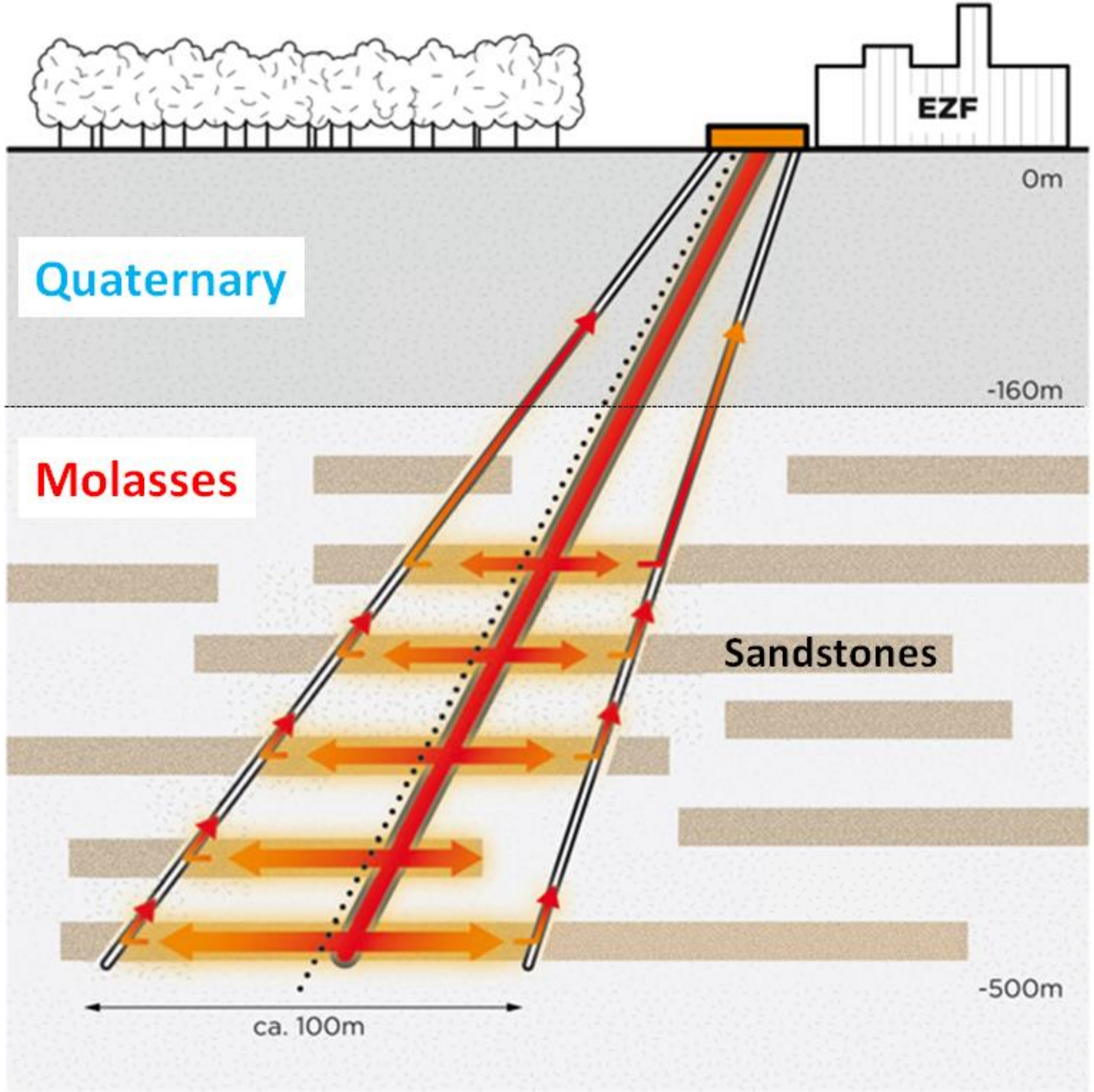
$$c_{Ca} \qquad \frac{\partial c_{Ca}}{\partial T} \qquad \frac{\partial^2 c_{Ca}}{\partial T^2}$$

3. Dissolution rate (*r*)

$$r_{calcite} = -\frac{\partial^2 (c_{Ca} - c_{Mg})}{\partial T^2} (\nabla T)^T \phi \mathbf{D} \nabla T + \frac{\partial (c_{Ca} - c_{Mg})}{\partial T} \left[(1-R)\phi \frac{\partial T}{\partial t} - \nabla \cdot \left(\left(\phi D_{dif} - C_a^{-1} \lambda \right) \nabla T \right) \right]$$

PILOT PROJECT



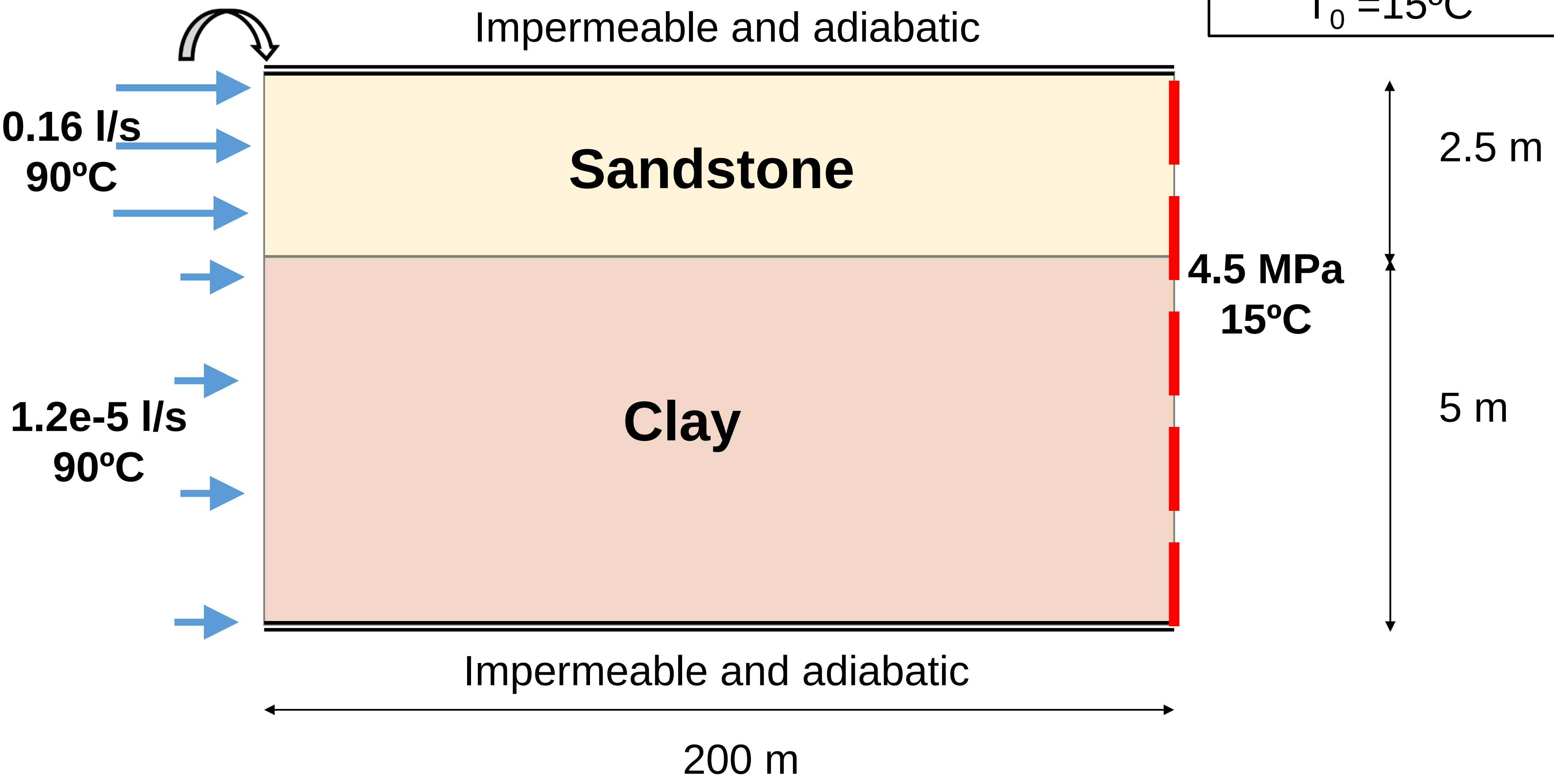


INJECTION: 0 - 216 days

EXTRACTION: 216 - 365 days

TH MODELLING

Initial conditions:
P_{l0} = 4.5 MPa
T_0 =15ºC



CONCENTRATION

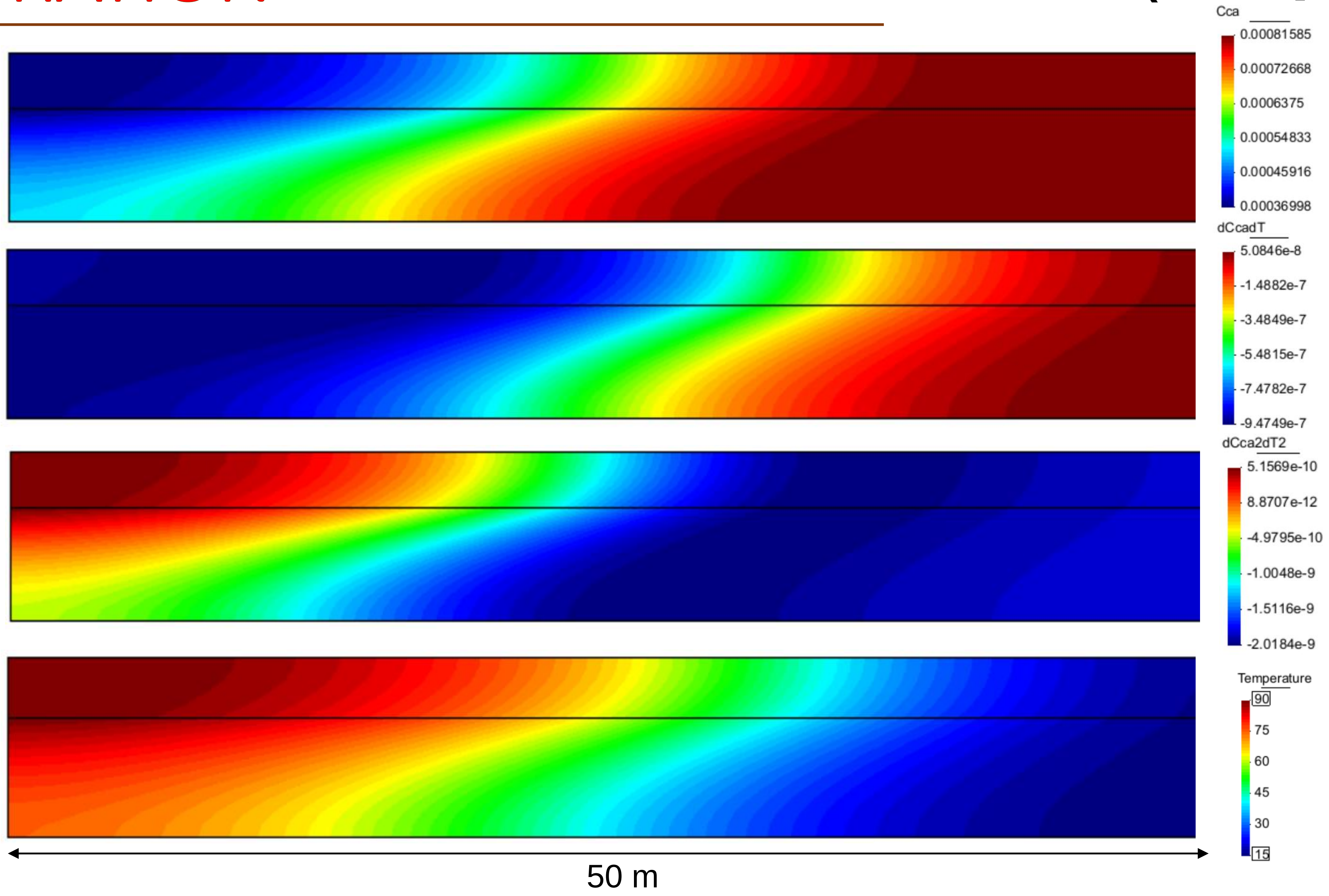
INJECTION (216 days)

$$c_{Ca}(T)$$

$$\frac{\partial c_{Ca}}{\partial T}(T)$$

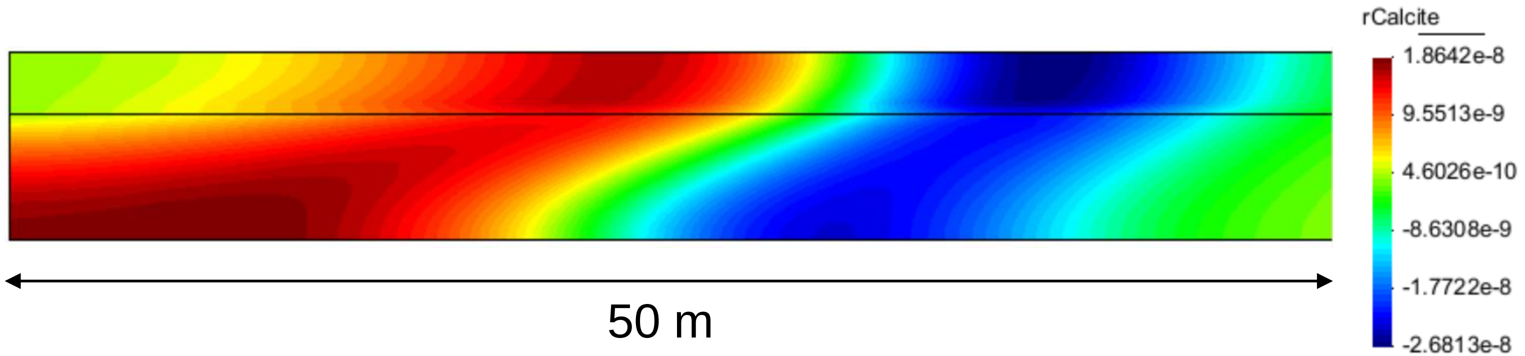
$$\frac{\partial^2 c_{Ca}}{\partial T^2}(T)$$

$$T$$

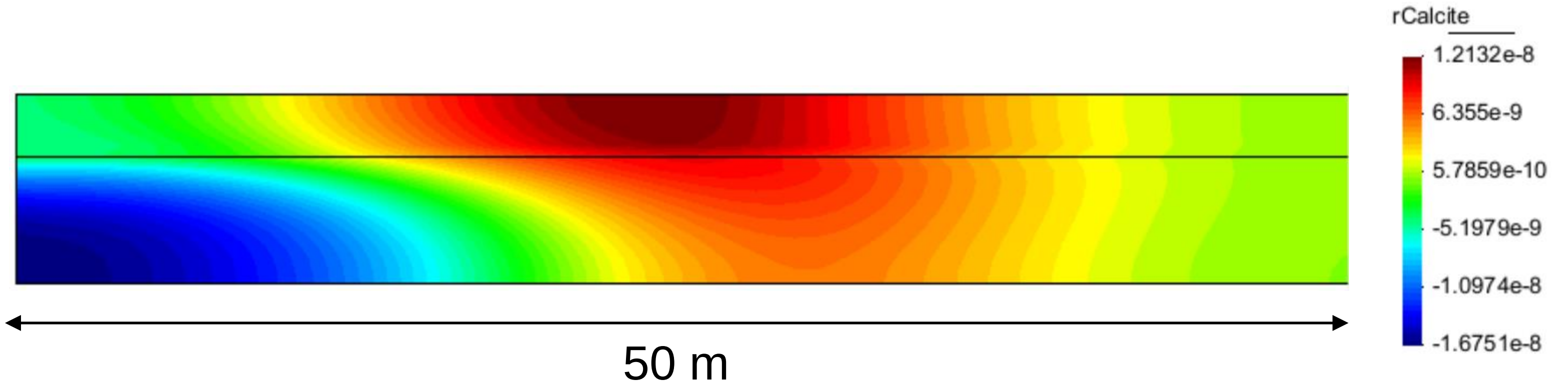


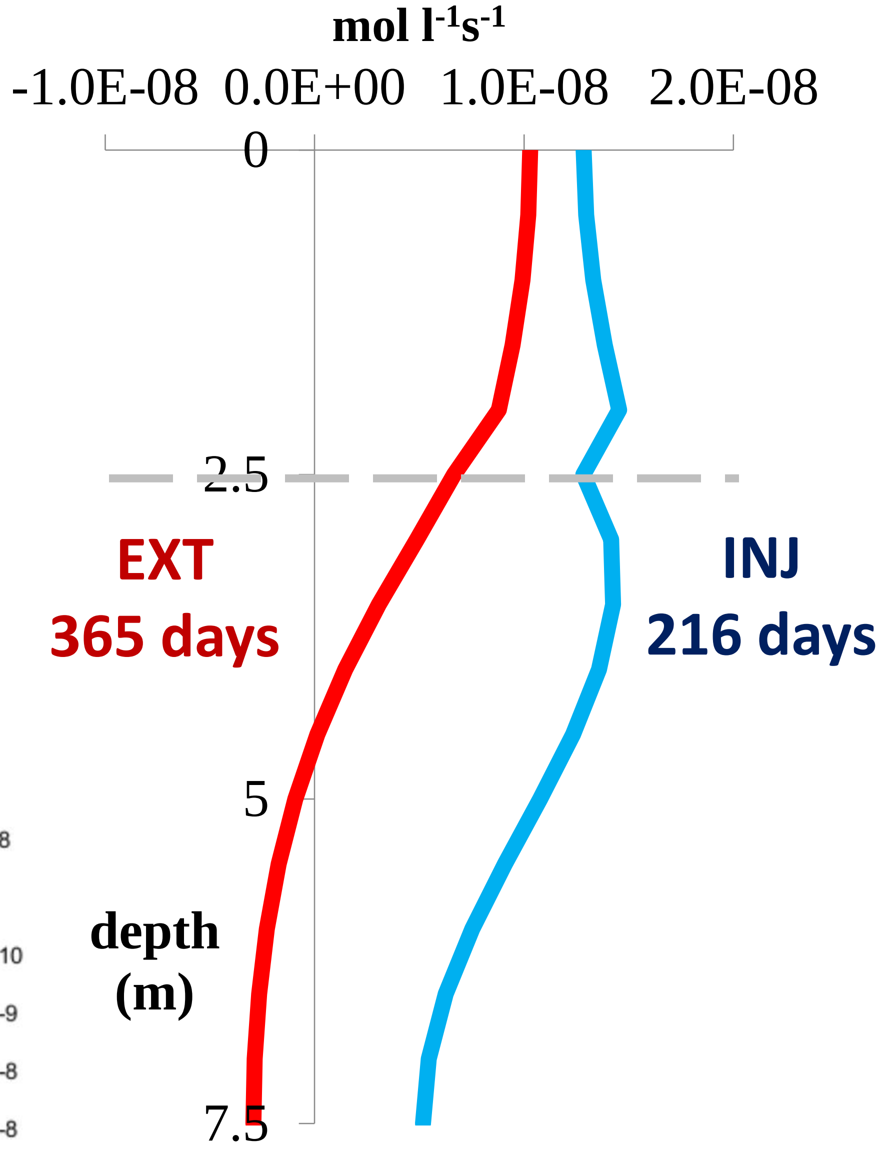
$$r_{total} = r_{mixing} + r_{heat\ cond} + r_{heat\ retard}$$

INJECTION (216 days)



EXTRACTION (365 days)





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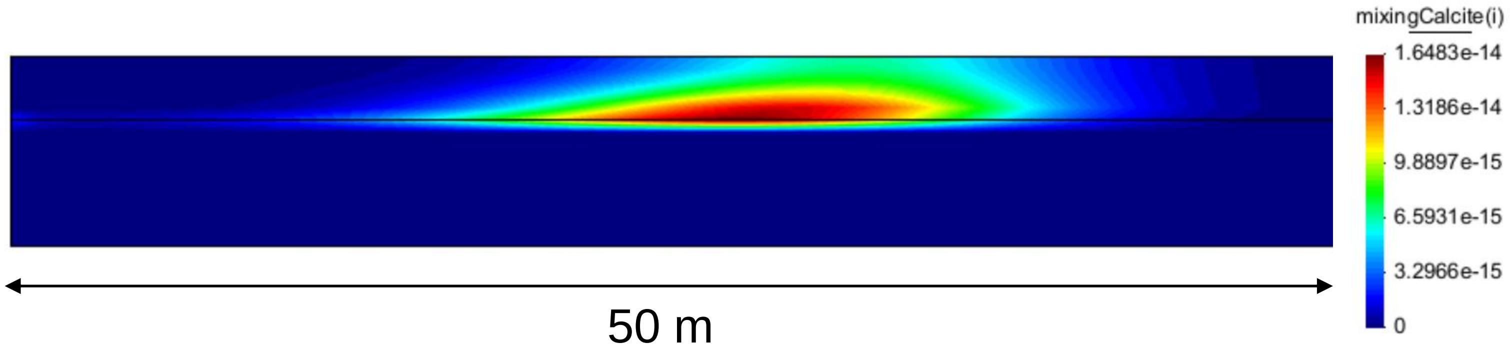

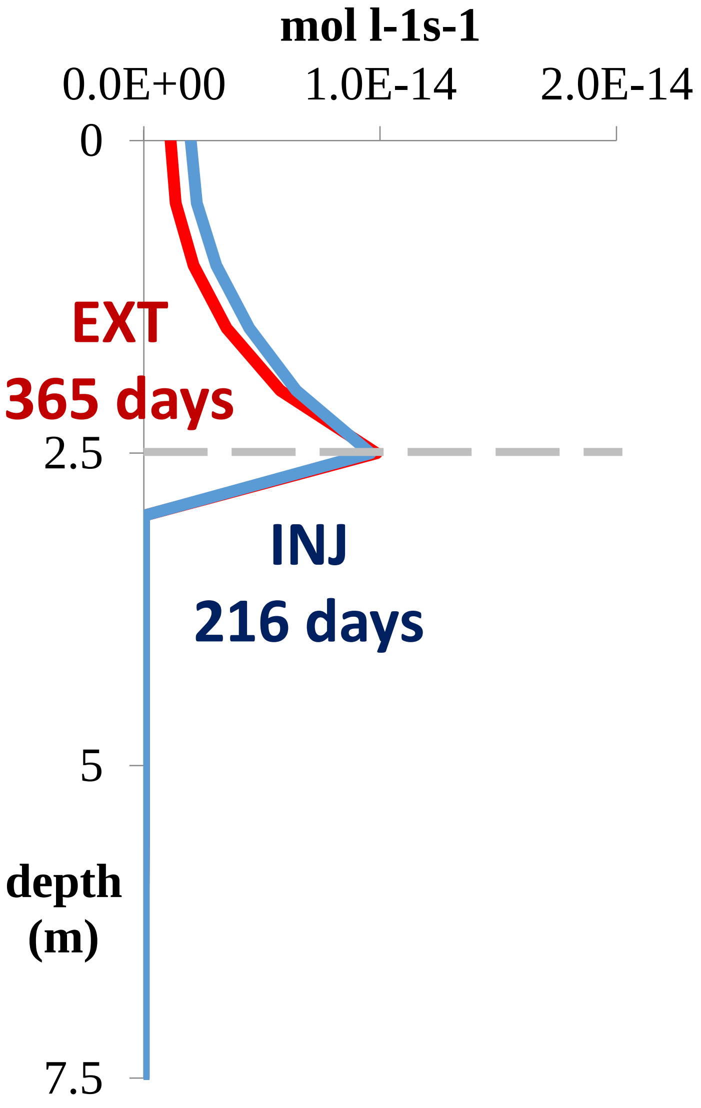

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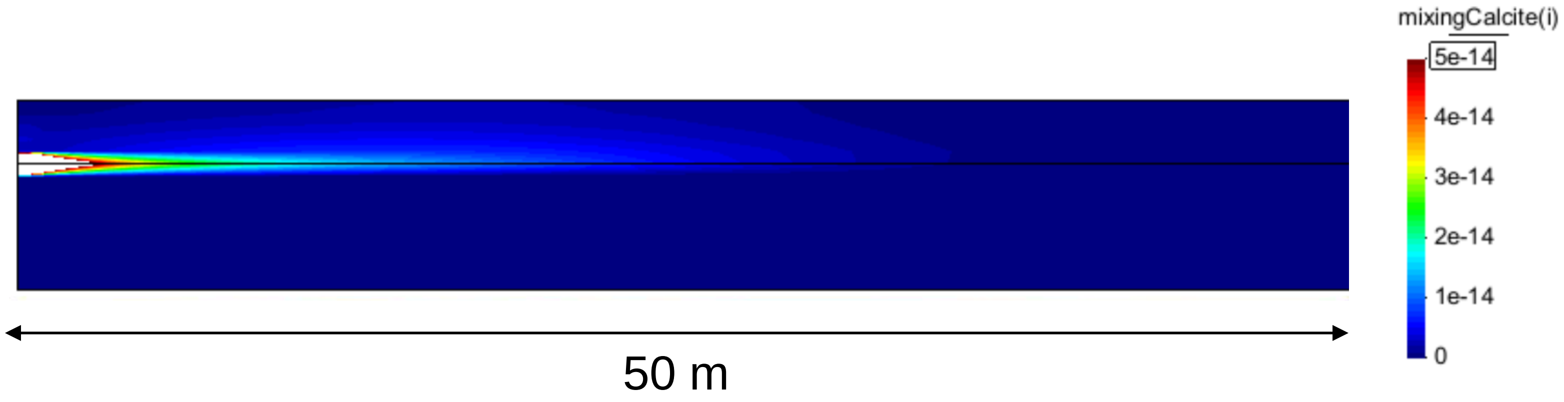

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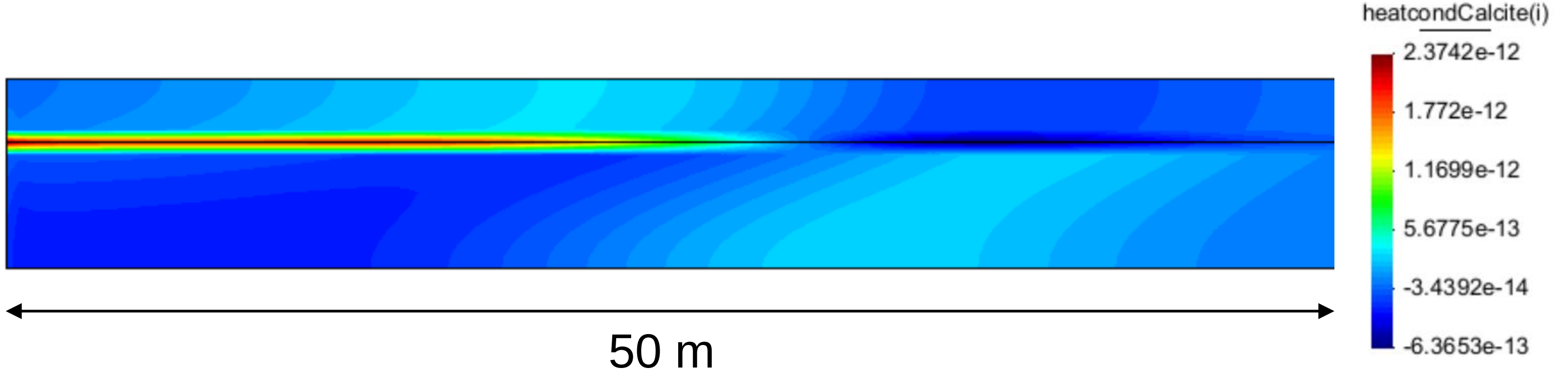

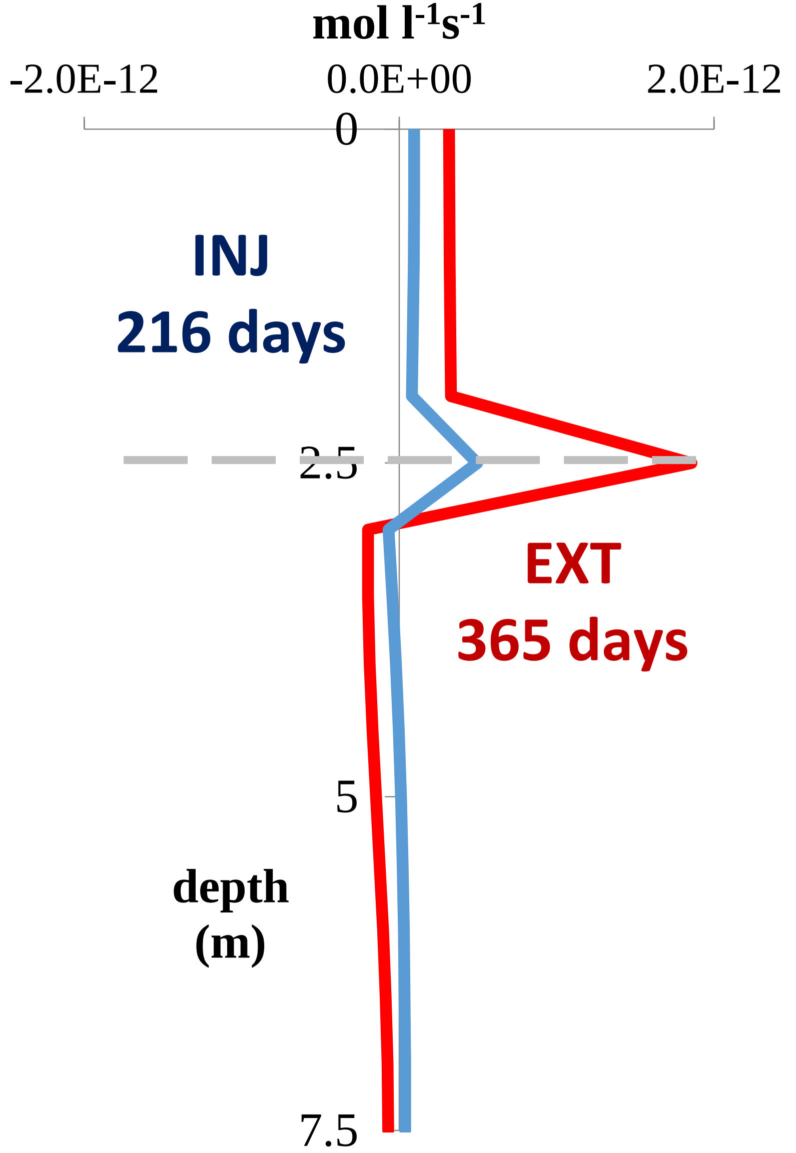

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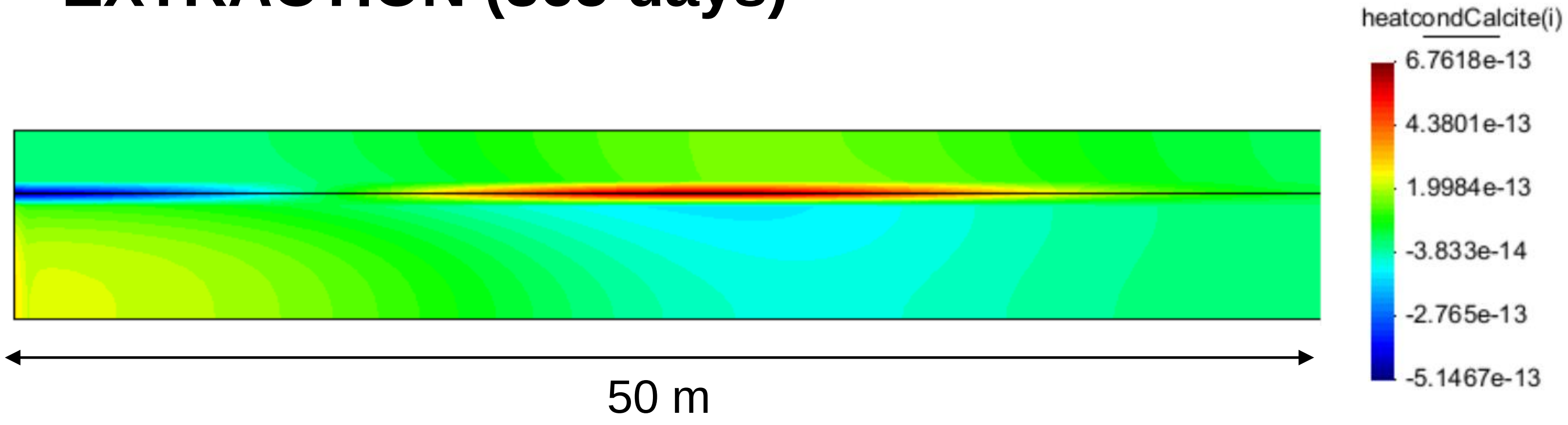

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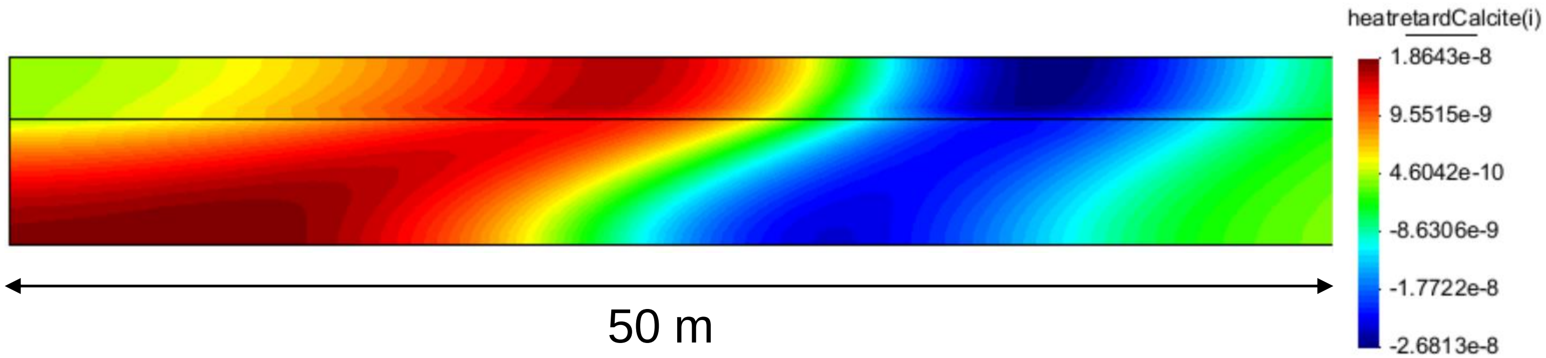

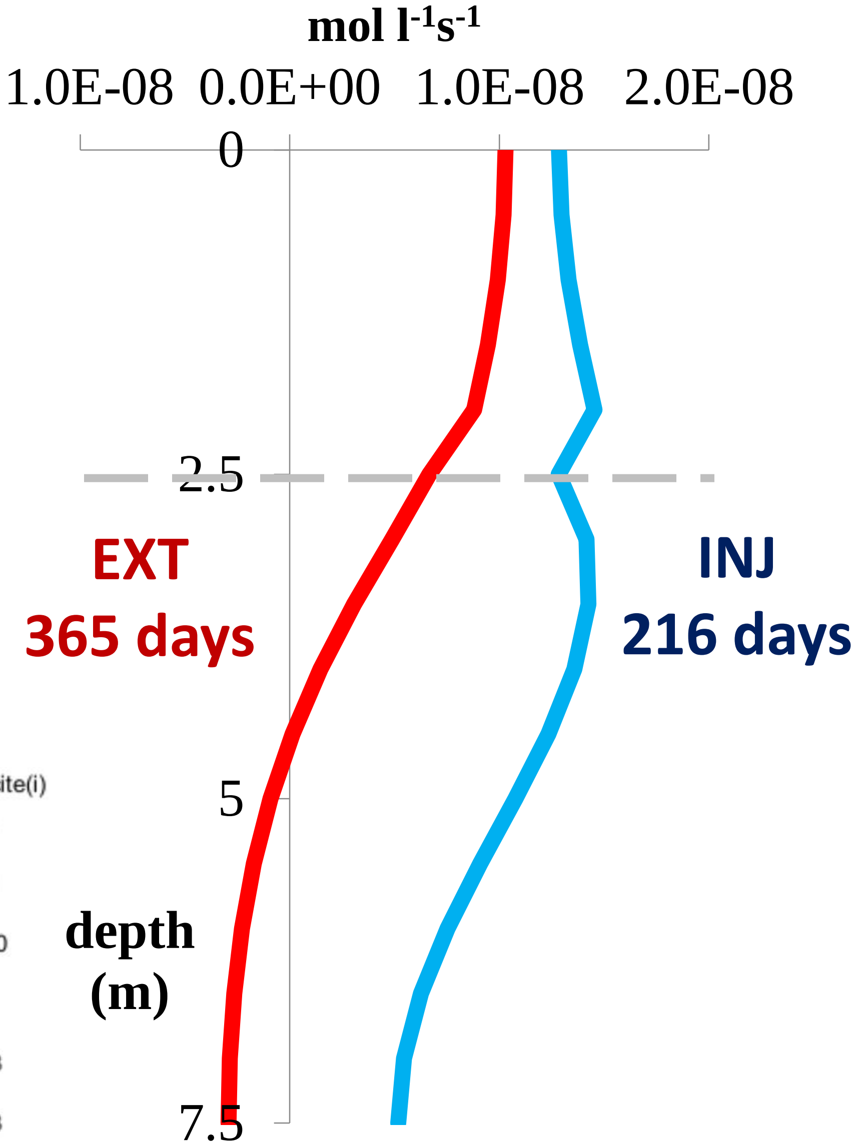

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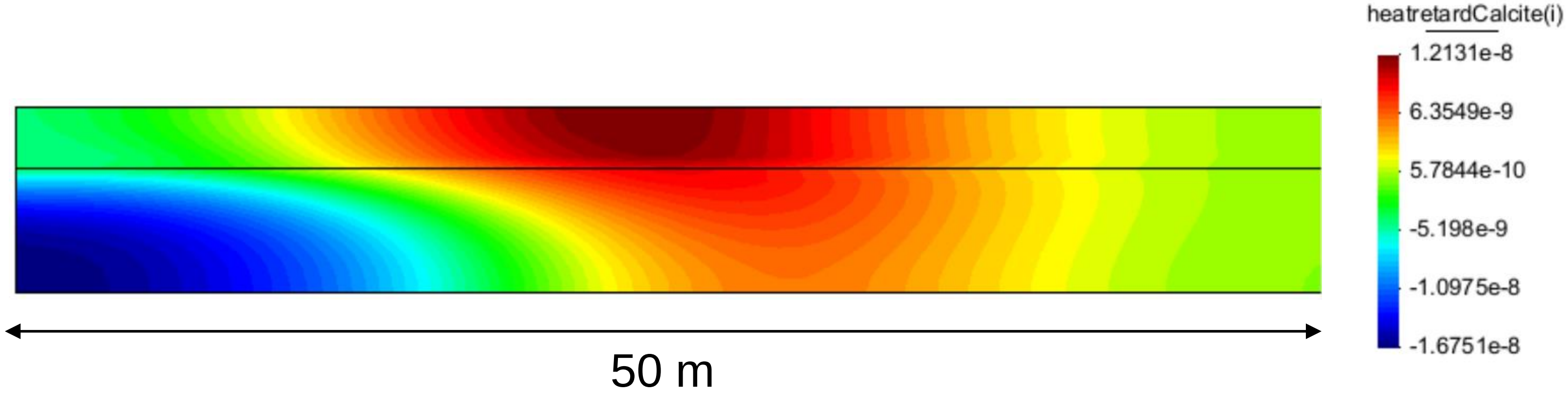

CONCLUSIONS

- If there are only aqueous and mineral reactions in equilibrium, we can deduce a (semi-)analytical solution for Thermo-Hydro-Chemical models

- In closed systems (only one end member), the dissolution rate requires the calculation of
  - Thermo-hydraulics ($\partial T/\partial t, \nabla T, \nabla^2 T$)
  - Concentration-temperature relations ($\partial c/\partial T, \partial c^2/\partial T^2$)

- Three terms in the dissolution rate: Mixing, Heat retardation, Heat conduction

- In general precipitation/dissolution is low, although sometimes it can go to infinity

THANK YOU