A thermo-poroelastic finite element analysis of fluid injection depending on fluid temperature and injection scenarios

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Introduction

The subsurface **fluid injection** can change pore pressure and underground stress, which may induce fault slip

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The **temperature of injected fluid** can control pore pressure and underground stress by thermo-poroelastic effect of fluid injection

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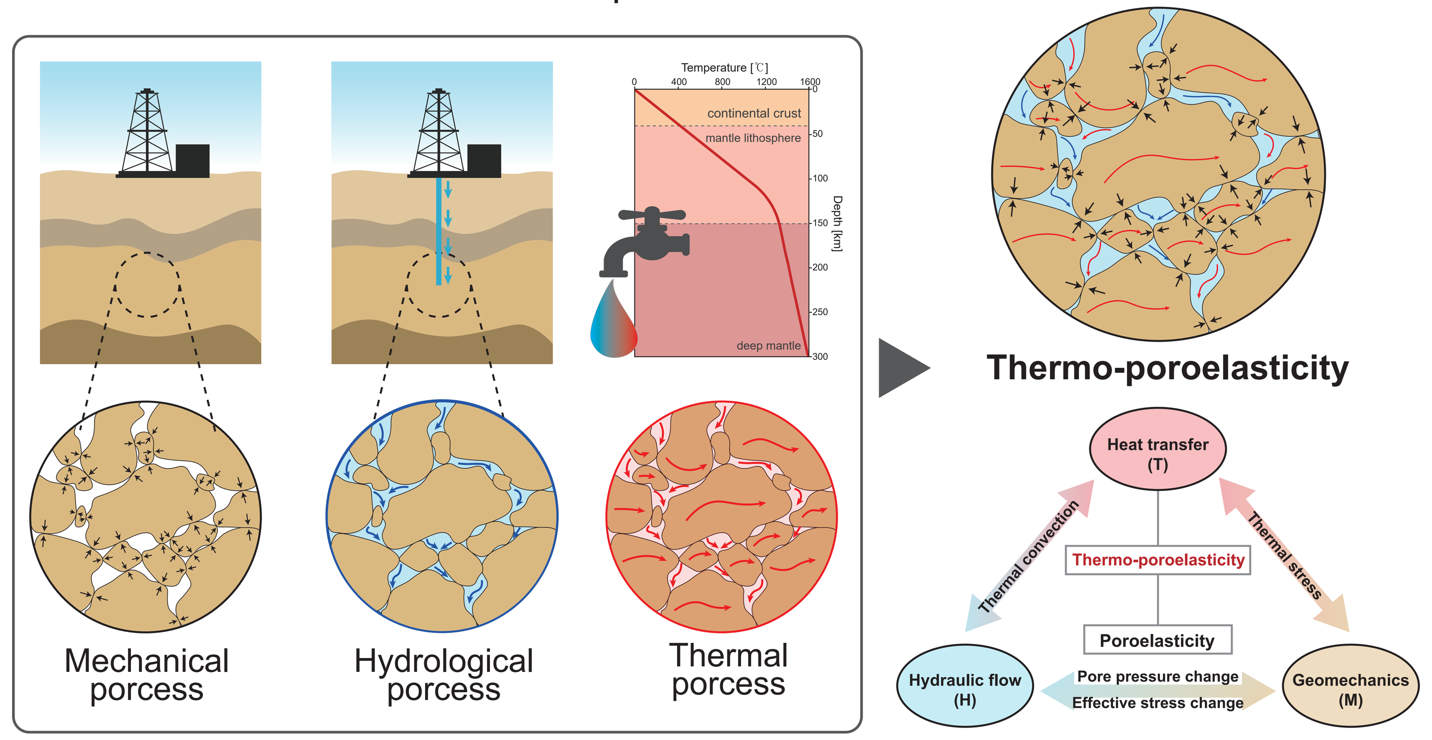
That explains the **interaction** between **pore fluid flow** and **elastic deformation** in a porous medium



Real natural environments are composed of complex relationships, so numerical simulations considering multiphysics are necessary. When artificial fluid injection, it is required to consider the relationship between the fluid and the pore skeleton, the temperature of the injected fluid, or the geothermal gradient.

Method

Governing equation(1) Equilibrium equation

$$\left(K+\frac{G}{3}\right)u_{k,ki}+Gu_{i,kk}-3K\beta_s T_{,i}-\alpha p_{,i}=0$$

Governing equation(2) Fluid flow equation

$$-\frac{\kappa}{\eta}p_{,kk}+\alpha\frac{\partial\varepsilon_V}{\partial t}+S_s\frac{\partial p}{\partial t}-(\phi 3\beta_f+(\alpha-\phi)3\beta_s)\frac{\partial T}{\partial t}=0$$

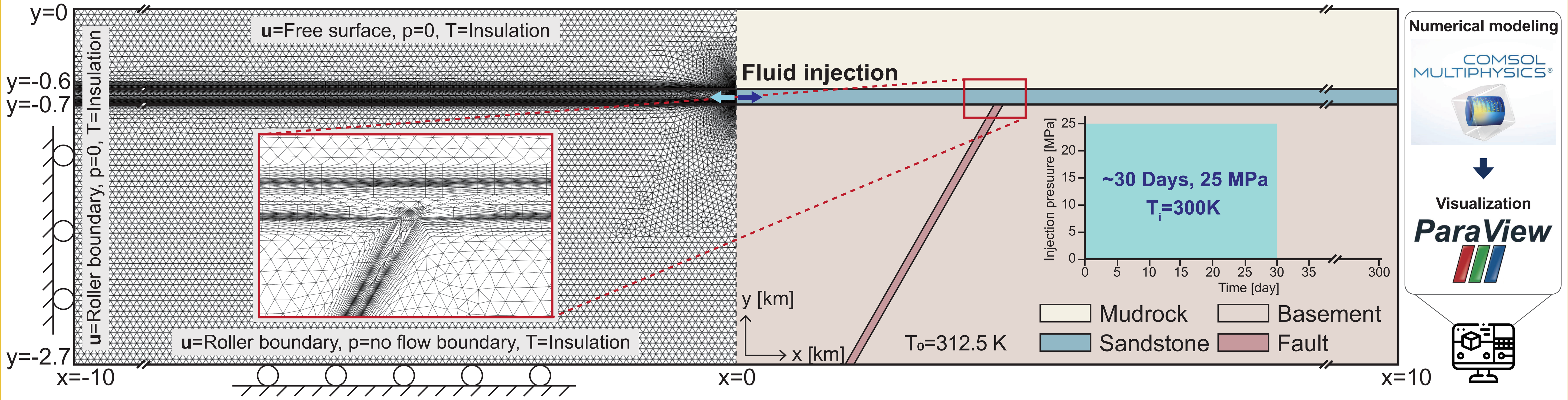
Governing equation(3) Heat energy balance equation

$$\rho C_T\frac{\partial T}{\partial t}-k_T T_{,kk}=0$$

	Variable Parameters	Unit		Variable Parameters	Unit
K	Bulk modulus	Pa	C_T	Heat capacity	$Jkg^{-1}K^{-1}$
G	Shear modulus	Pa	k_T	Thermal conductivity	$Wm^{-1}K^{-1}$
κ	Permeability	m^2	β_f	Fluid thermal expansion coefficient	K^{-1}
η	Fluid viscosity	Pa · s			
α	Biot-willis coefficient	-	β_s	Solid thermal expansion coefficient	K^{-1}
S_s	Specific storage	Pa^{-1}			

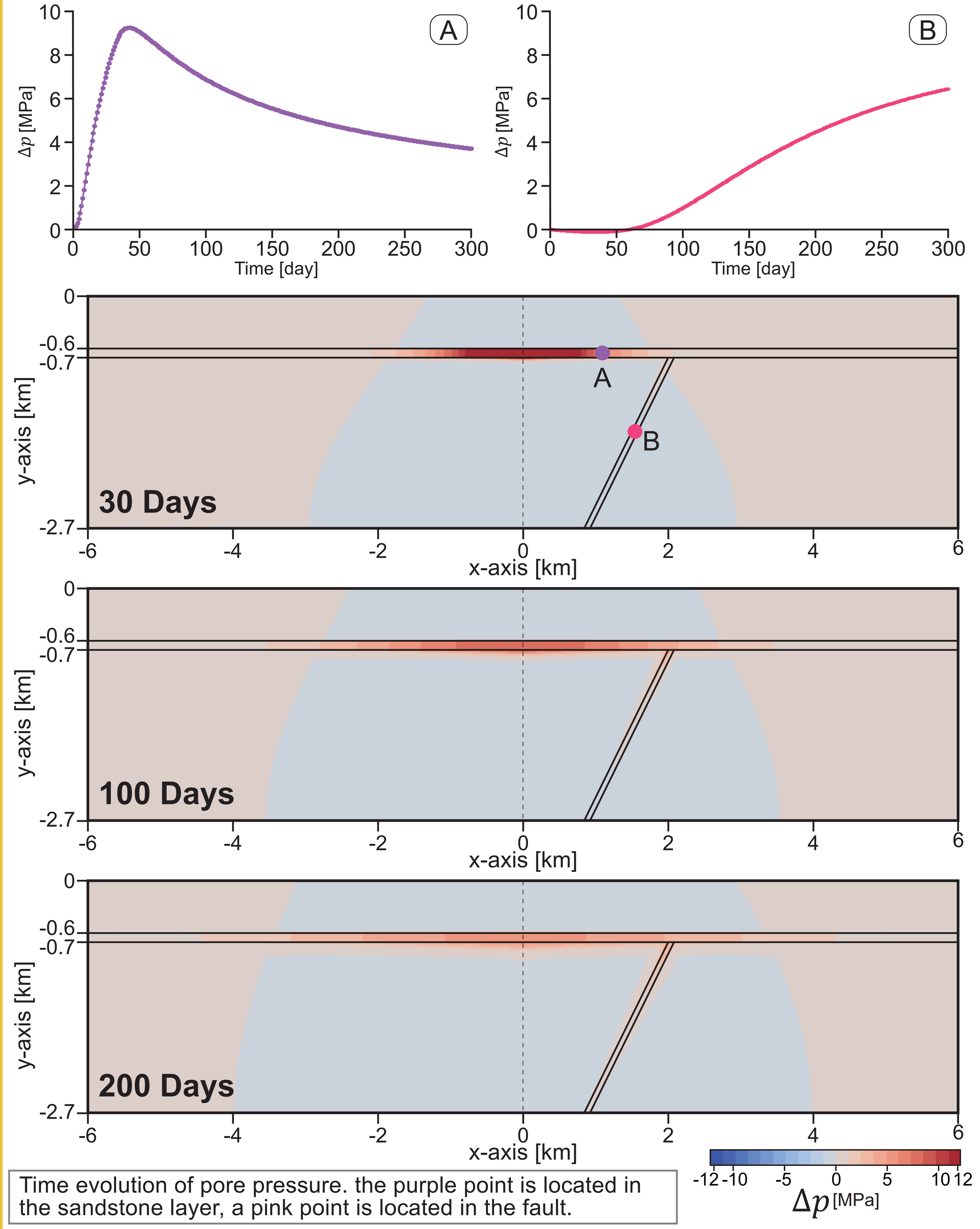
Thermo-poroelasticity equation consists of three governing equations. Governing equations (1) and (2) are fully coupled poroelasticity equations, and (3) is the heat energy balance equation. We didn't consider porosity evolution, and convective heat transfer effects were neglected.

Model set-up. Numerical model domain with three layers and mesh structure



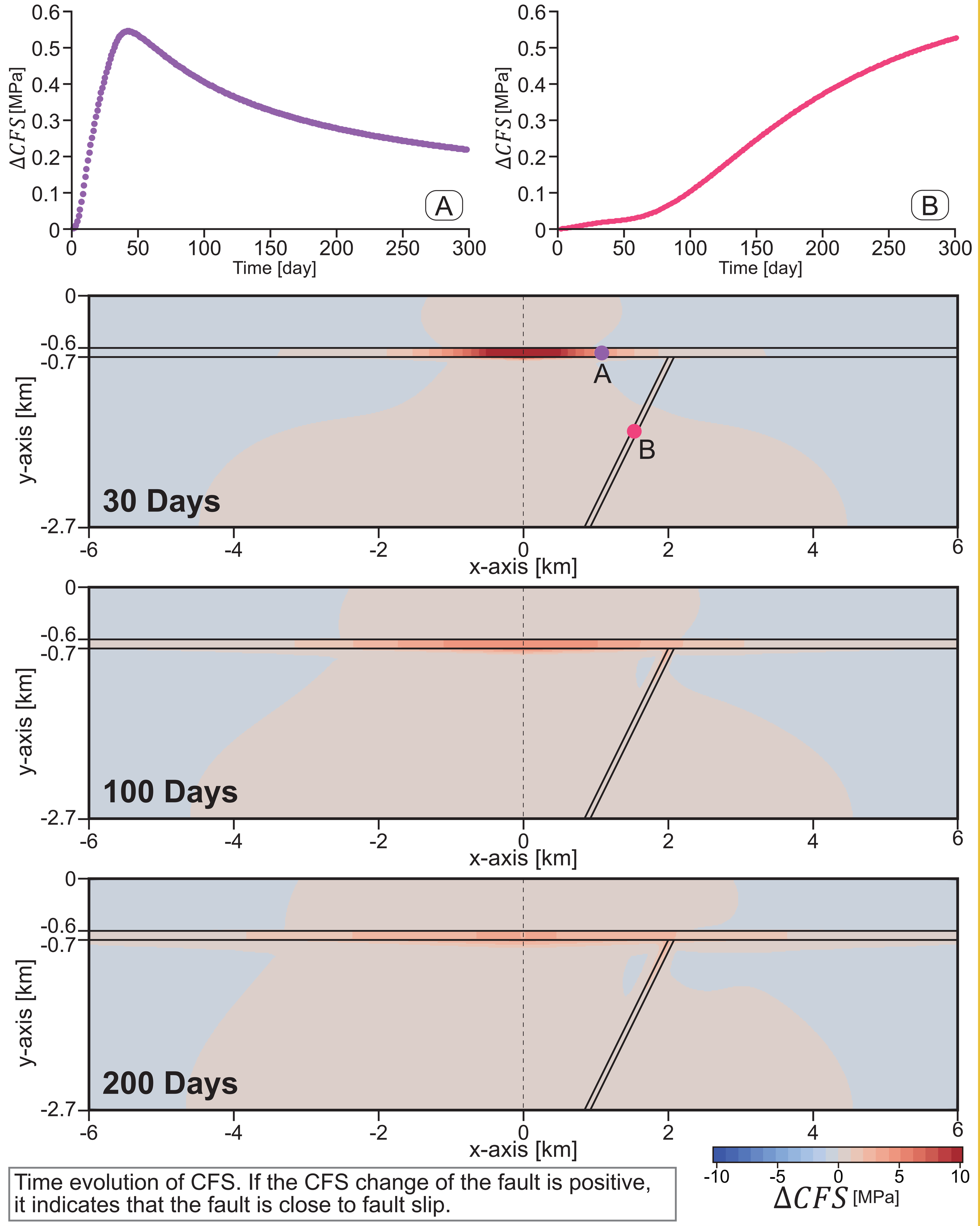
Numerical model. The left section shows the mesh and boundary conditions, and the red box magnifies the mesh structure near the junction of the sandstone layer and the fault. The right section shows a model domain and injection scenario. The numerical modeling is done using the finite element software COMSOL Multiphysics and the visualization is done using ParaView.

Results 1. Porepressure change(Δp)



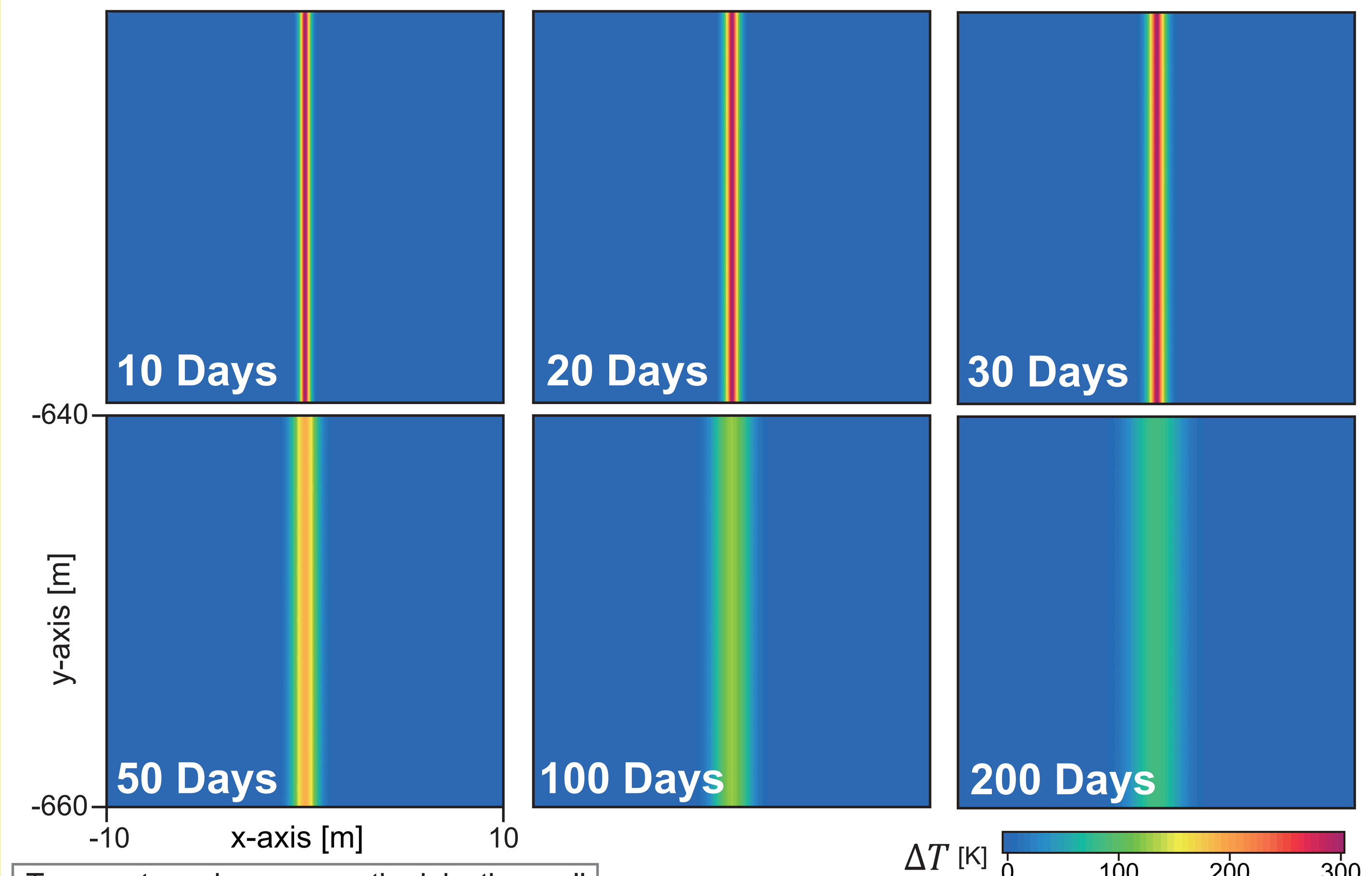
Time evolution of pore pressure. the purple point is located in the sandstone layer, a pink point is located in the fault.

Results 2. Coulomb failure stress change(ΔCFS)



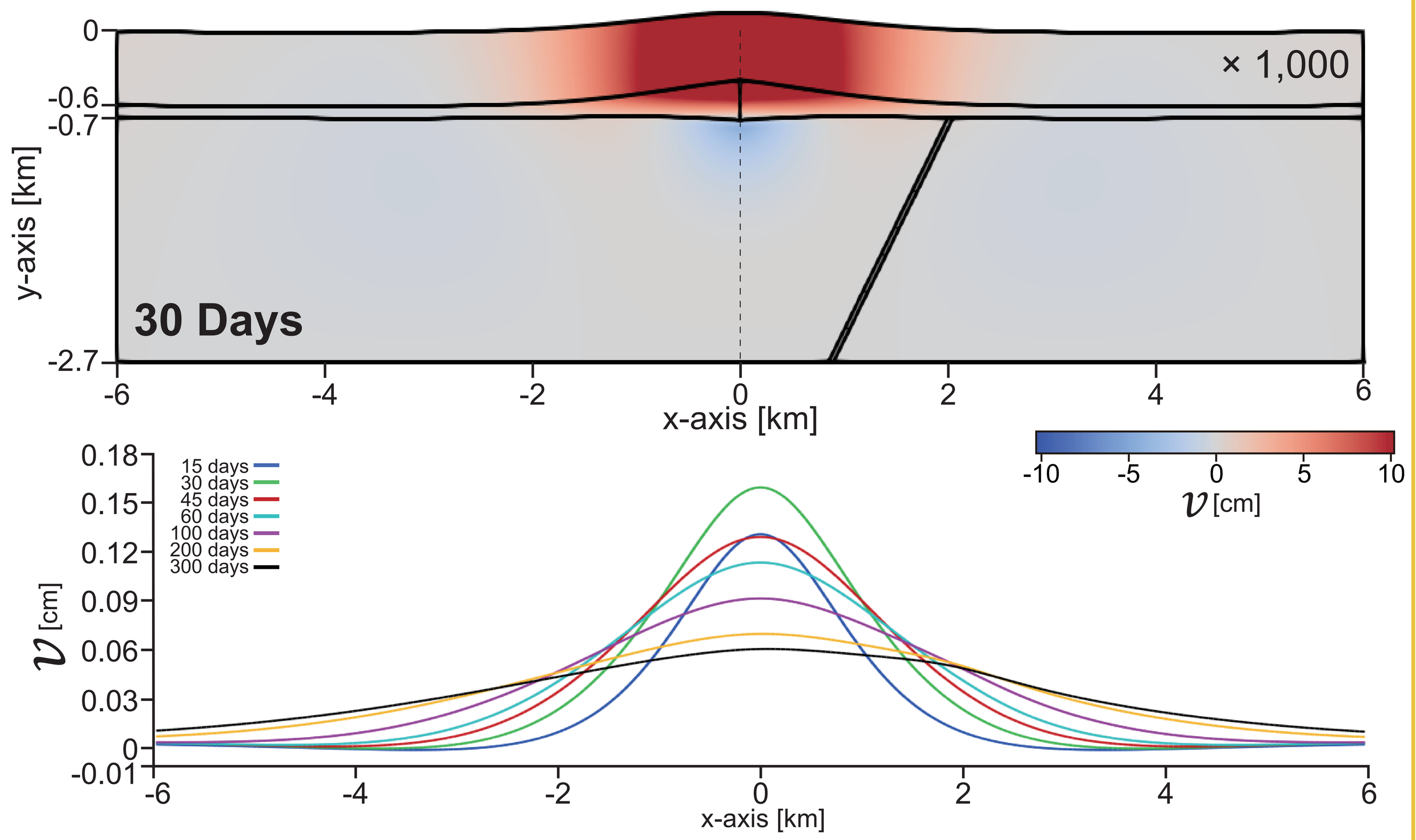
Time evolution of CFS. If the CFS change of the fault is positive, it indicates that the fault is close to fault slip.

Results 3. Temperature change(ΔT)



Temperature change near the injection well

Results 4. Vertical displacement(v)



Vertical displacement along the surface is exaggerated by 1,000 times to emphasize surface deformation.

Conclusion & Future works

- Use the thermo-poroelastic equation to calculate pore pressure, temperature, Coulombic fracture stress change, and vertical displacement in an artificial fluid injection environment.
- Shows that pore pressure, stress, etc. increase for a period of time after the end of fluid injection.
- This indicates the need for monitoring after the end of the fluid injection.
- In this study, the heat energy balance equation was not fully coupled to the fully coupled poroelasticity equation, but a fully coupled thermo-poroelastic equation should be considered for accurate calculations.
- It is also necessary to consider the evolution of porosity and permeability.

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