THMC$_{7.1}$ simulation of fluid exchange due to CO_2 leakage along faults during CO_2 geo-sequestration in saline aquifer

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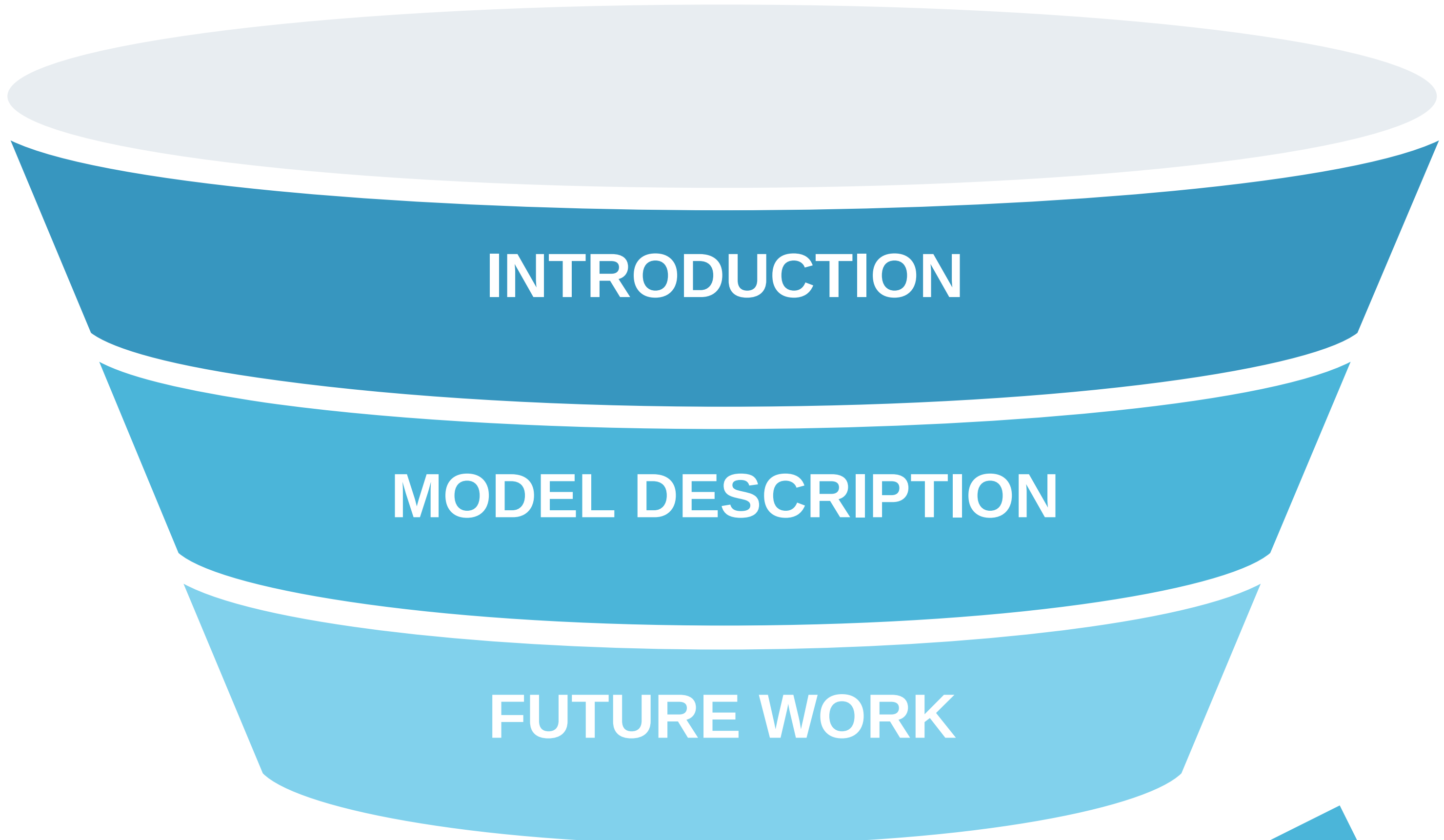
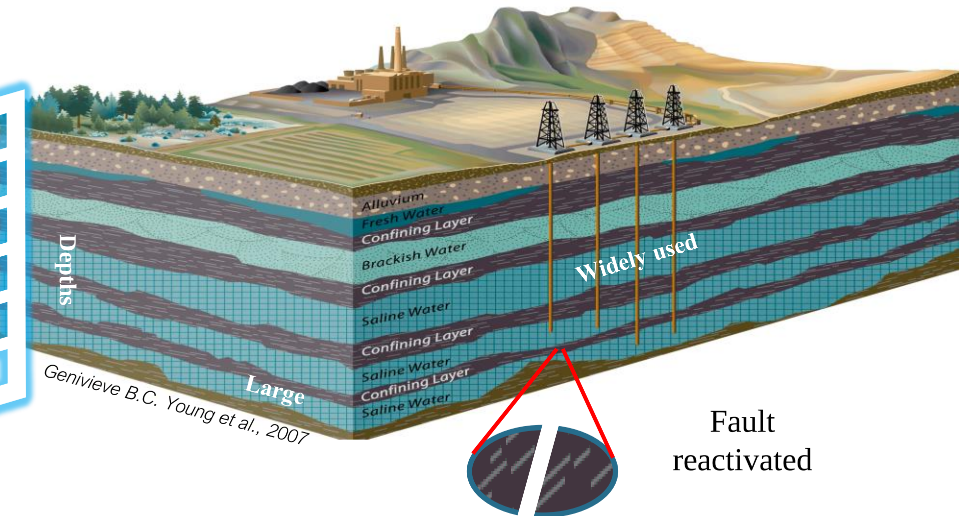
Date : 2024/03/29

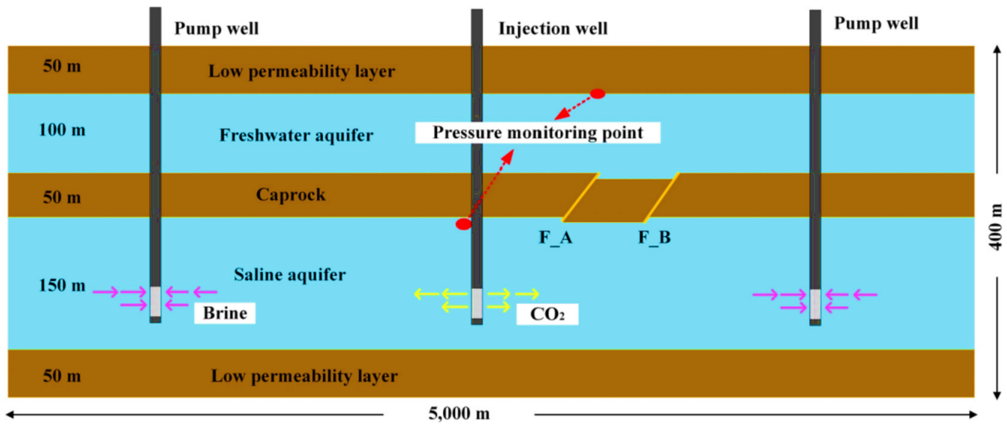
OUTLINE



INTRODUCTION



CO_2 leakage along fault was the largest risk of CO_2 sequestration (Miocic *et al.* (2016)).



Physical model descripts the fluid exchange (Zhang *et al.* (2018)).

CO_2 GEO-SEQUESTRATION

- **C**arbon **C**apture and **S**torage **(CCS)**
- Capturing carbon dioxide emissions
- Currently, this is the most effective way to reduce GHGs and mitigate the impacts of climate change.

- **Deep saline aquifers** is one of the main candidates to cut anthropogenic CO_2 emissions.
- **Caprock** is a natural barrier to prevent the injected CO_2 escaping from reservoirs.

FLUID EXCHANGE

Associated to **CO_2 leakage, brine** and **freshwater** would escape or lose along the fault from their respective formation.

MOTIVATION

- Recently, **do not have enough information to fully understand** what happens when we inject CO_2 into geological formations.

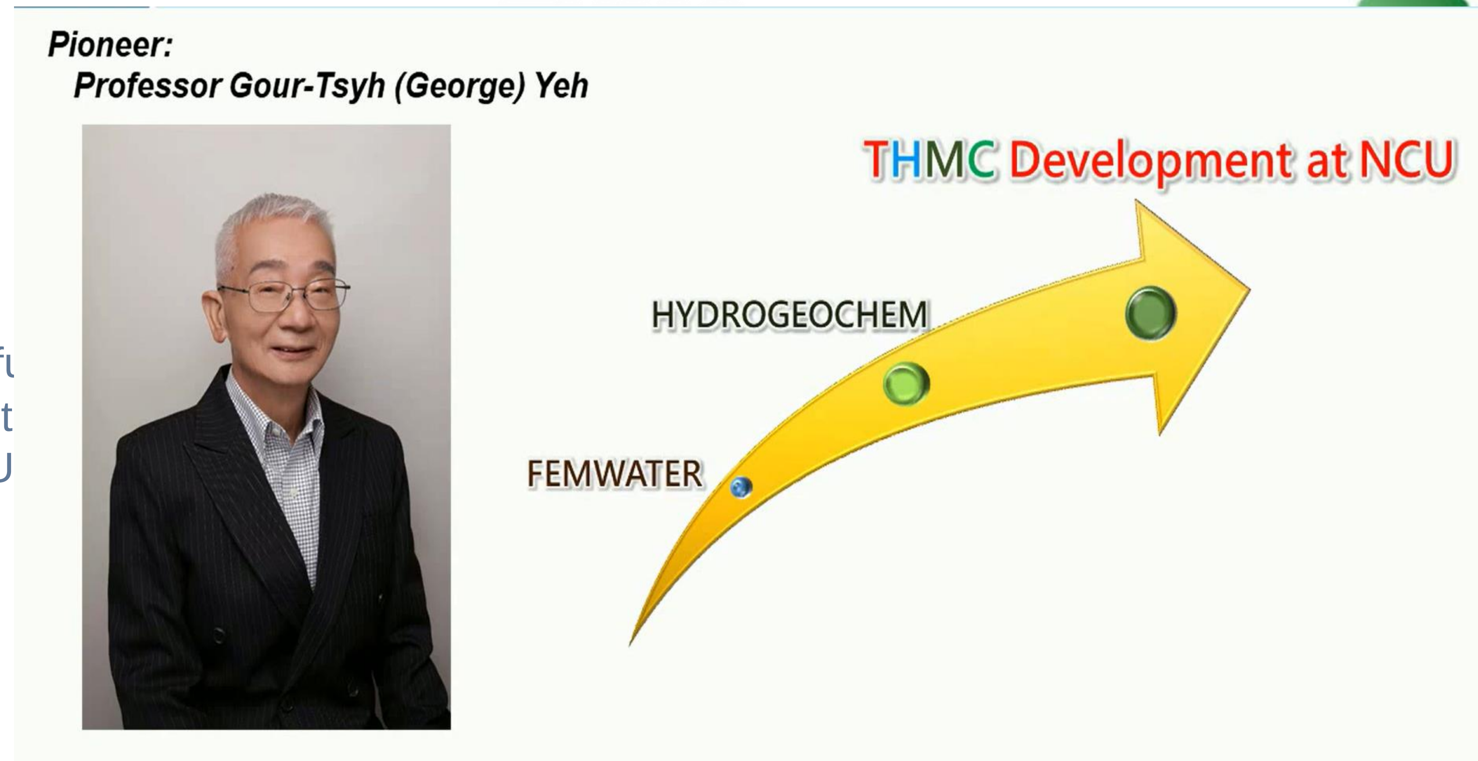
- Due to some **disadvantages of CO2 geo-sequestration** such as: leakage risk, monitoring and verification challenges, limited storage locations, high costs,...

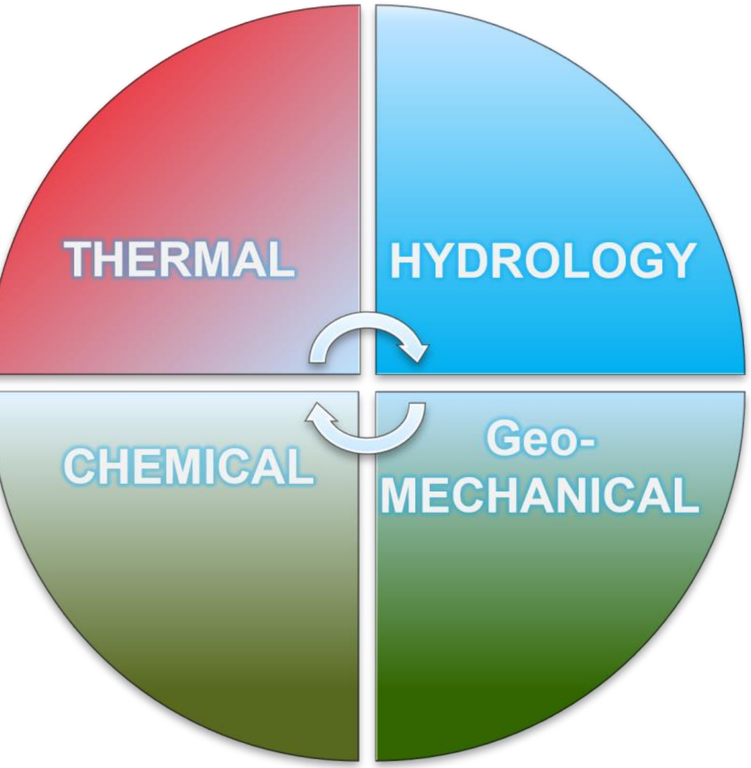
- Improving the **reliability and safety** of geo-sequestration sites.

- Ensuring **the long-term security of CO2 storage** and minimizing **environmental risks**.

INTRODUCTION

THMC7.1 is a 3D finite element model of fu processes are developing by **CAMRDA** - Cent Research Development and Application at NCU





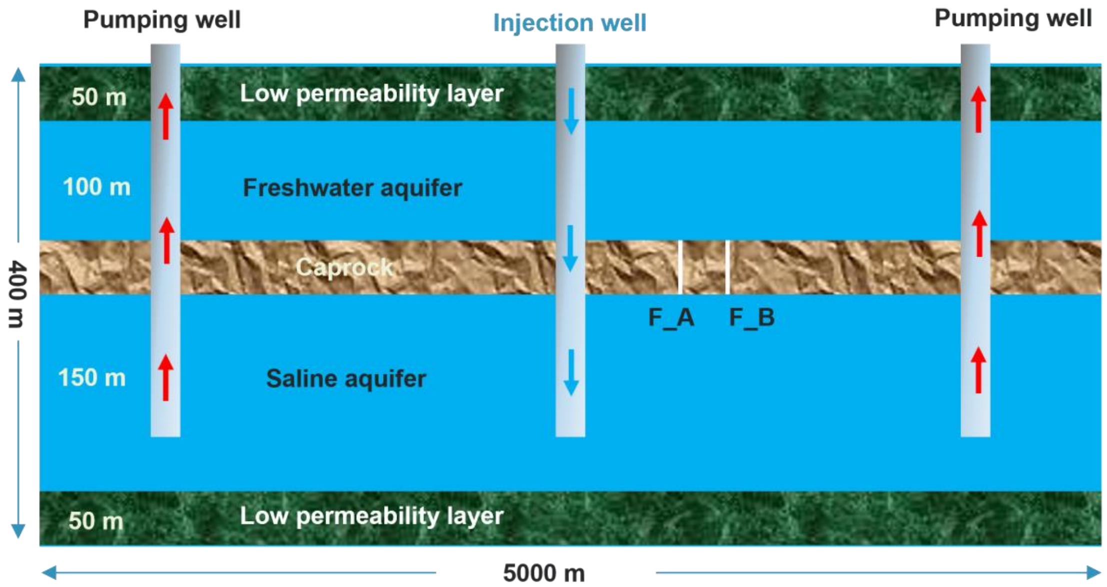
- Revolutionizes the user experience within the complex groundwater simulation process.
- With userfriendly interface can facilitate the modeling and Analysis of complex THMC systems.
- Allowing engeneers to tackle larger scale problem

OBJECTIVE

- Plan to closely examine how fluids move and potentially leak along two faults in the caprock layer when CO2 is stored in saline aquifer.

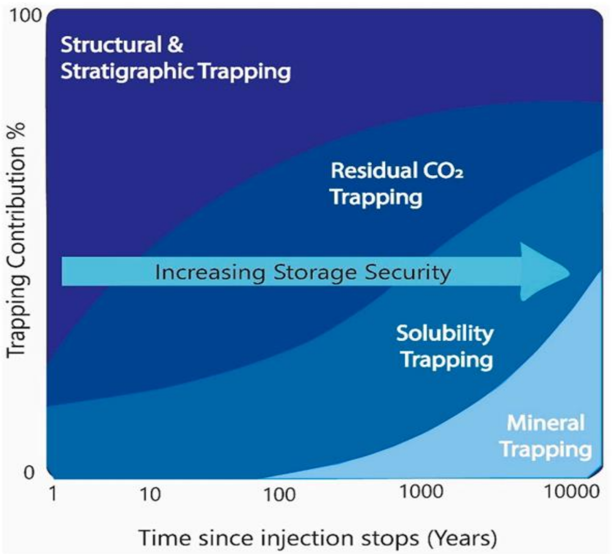
- Employ a 3-D numerical model based on THMC 7.1 to investigate fluid exchange related to CO_2 leakage along faults.

PHYSICAL MODEL



- Two faults exist in the caprock:
  + Depth of 200m
  + Fault zone extents 130m and has the width of 10m
  + Vertical fault
- Injection well is located in the center of the physical model
- The distence between injection well and pump wells is 2000m
- The distence between F_A and the injection well is 500m

A fluid exchange would certainly occur, associated to CO_2 leakage along activated fault.



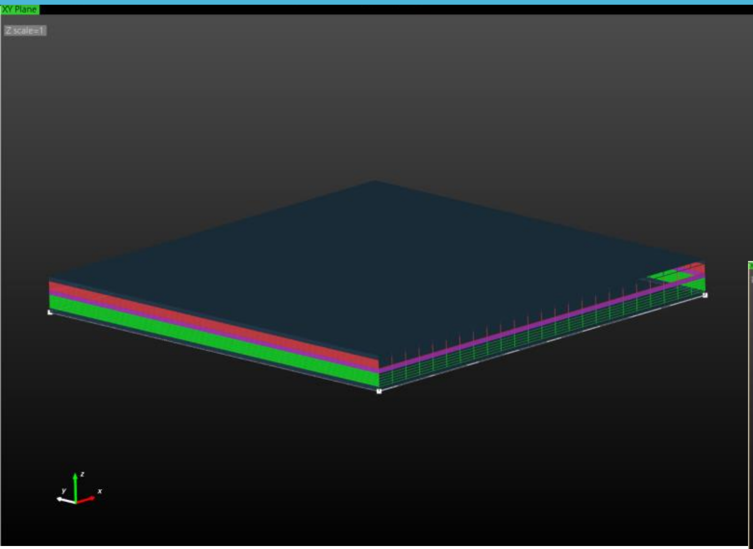
Contribution of trapping mechanisms in a CO_2 storage site at different time scales (IPCC, 2005).

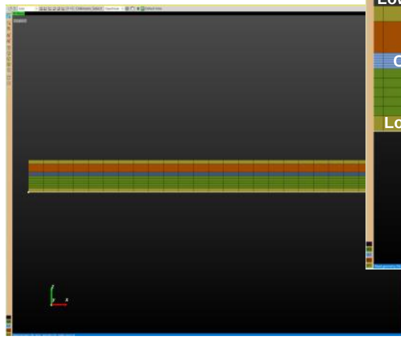
Structural and Stratigraphic Trapping: CO_2 is physically trapped under impermeable rock layers in a similar manner to natural gas.

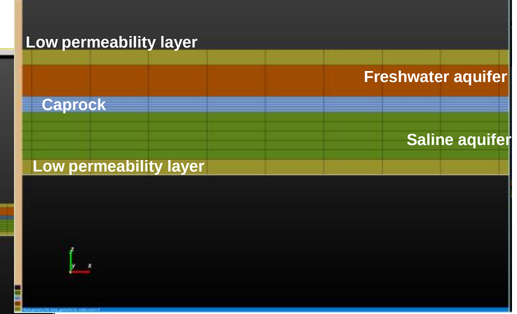
Residual Trapping: CO_2 molecules are trapped in the pore spaces of the rock due to capillary forces.

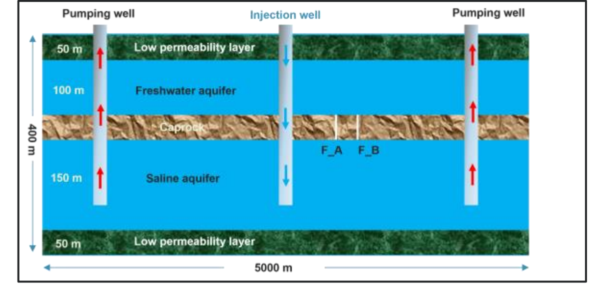
Solubility Trapping: Dissolved CO_2 in groundwater forms a slightly denser solution that moves downwards, further away from the atmosphere.

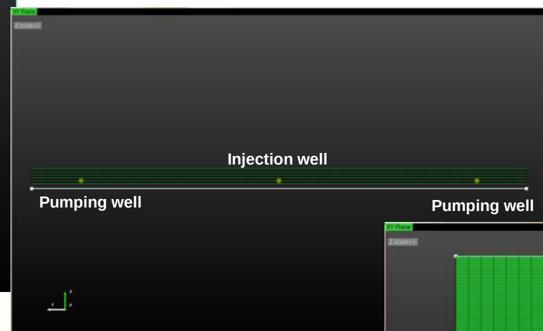
NUMERICAL MODEL

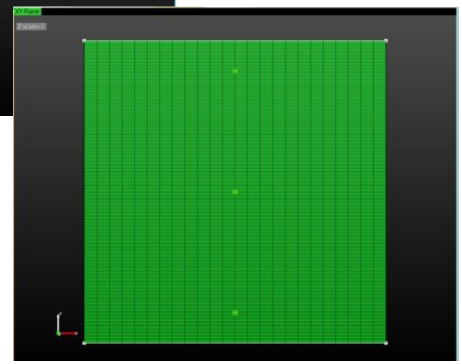


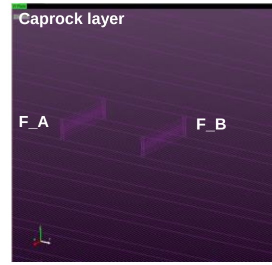


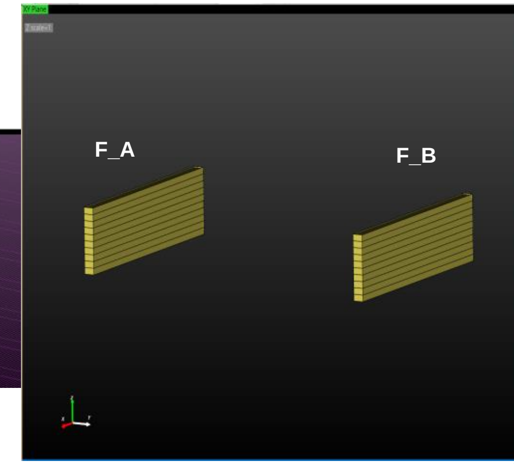










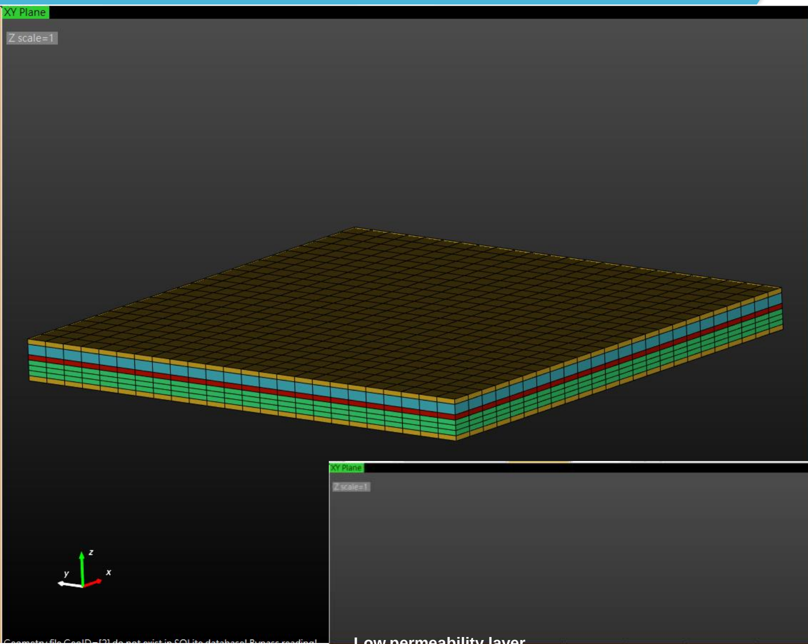


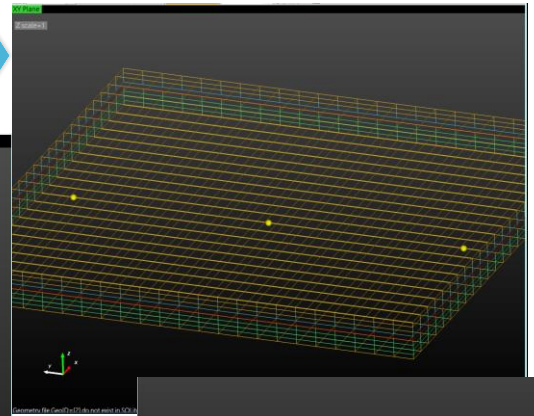
- **Grid blocks** consisted: 216.000 (500*24*18).
- The **mesh refinement** was carried out around the faults and injection/pump wells.
- **Isothermal conditions** were used for simplifying.

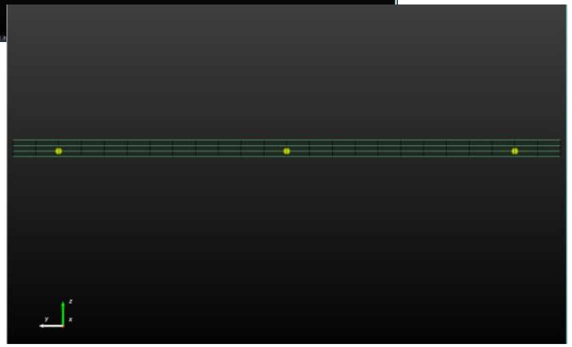
INITIAL BOUNDARY:

- **Impermeable boundaries** were set on the top and bottom surfaces.
- **Closed boundaries** were set at the other surfaces.

NUMERICAL MODEL







HORIZONTAL CO2 PLUME

- **Grid blocks** consisted: 4032 (24*24*7).
- **Isothermal conditions** were used for simplifying.

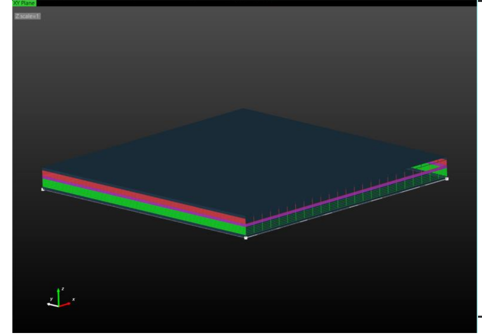
- **Impermeable boundaries** were set on the top and bottom surfaces.
- **Closed boundaries** were set at the other surfaces.

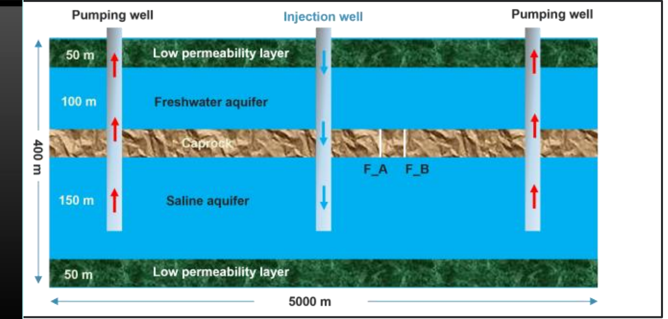
Purpose:

- How CO_2 disperses within the saline aquifer post-injection
- Buoyancy forces effect
- A baseline understanding

NUMERICAL MODEL

GOVERNING EQUATION





Multiphase fluid flow (H):

The basic mass conservation equation used in this model was shown as following:

$$\frac{\partial \hat{\rho}_\alpha \phi S_\alpha}{\partial t} + \nabla \cdot (\hat{\rho}_\alpha \boldsymbol{V}_\alpha) + \nabla \cdot (\hat{\rho}_\alpha \phi S_\alpha \boldsymbol{V}_s) = M^\alpha, \alpha \in \{L\}$$

in which $M^\alpha = \sum_{i \in \{M_\alpha\}} M_i^\alpha$

(Suk and Yeh (2007, 2008); Tsai and and Yeh (2012, 2013))

ρ_α: the density of α-th fluid phase ($\mathrm{ML^{-3}}$)
ϕ :the volume fraction (-)
S_α : the normalized saturation of α-th fluid phase (-)
$\boldsymbol{V}_\alpha$: the Darcy velocity of α-th fluid phase ($\mathrm{ML^{-1}}$)
$\boldsymbol{V}_s$: the Darcy velocity of the solid ($\mathrm{ML^{-1}}$)
M^α: the sum of the artifical source/sink rate of all species in α-th fluid phase ($\mathrm{ML^{-3}T^{-1}}$)

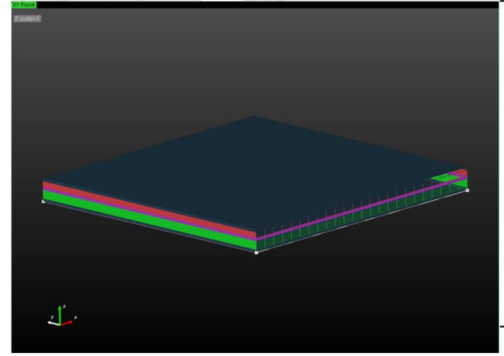
$$\boldsymbol{V}_\alpha = -\frac{k_{r\alpha}}{\mu_\alpha} \boldsymbol{k} \cdot (\nabla p_\alpha + \rho_\alpha g \nabla z), \qquad \mathbf{V}_s = \frac{d\boldsymbol{u}}{dt}$$

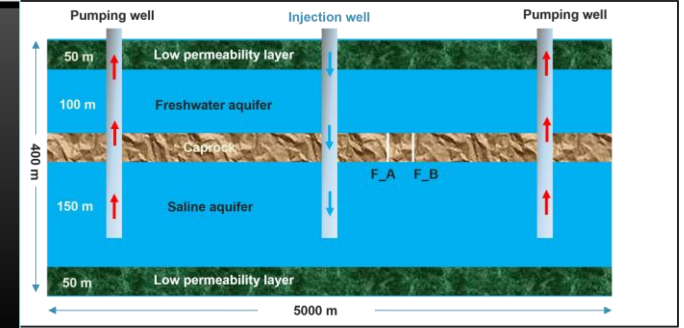
ρ_α: the relative permeability of i-th fluid phase (-)
$\boldsymbol{k}$: the permeability of porous medium ($\mathrm{L^2}$)
μ_α: the viscosity of α–th fluid ($\mathrm{ML^{-1}T^{-1}}$)
P_α: the pressure of α–th fluid phase ($\mathrm{ML^{-1}T^{-1}}$)
g: the gravitational acceleration ($\mathrm{LT^{-2}}$)
z: the potential head (L)
$\boldsymbol{u}$: the displacement of the media (L)

1. Solving mass conservation
2. Compute new k_{ra}; μ_a; ρ_a
3. Calculate M^α, $\boldsymbol{V}_\alpha$

NUMERICAL MODEL

Initial conditions



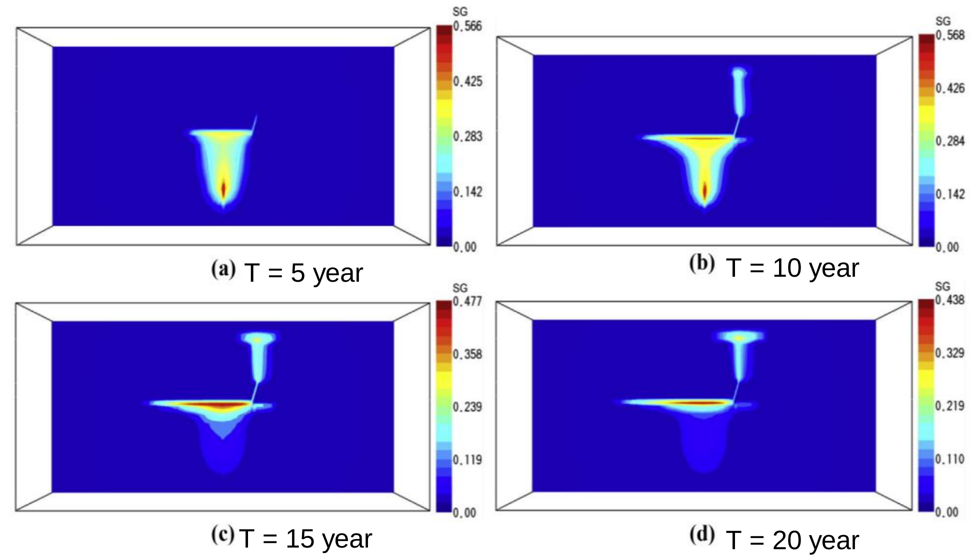


Initial conditions	Value
Temperature	49 °C
Pressure in saline aquifer	9 Mpa
Salt mass fraction of saline aquifer	0.6%
CO_2 injected rate	10 kg/s
Brine pump rate	5 kg/s
Simulation time	20 years

Table 1
Input parameters.

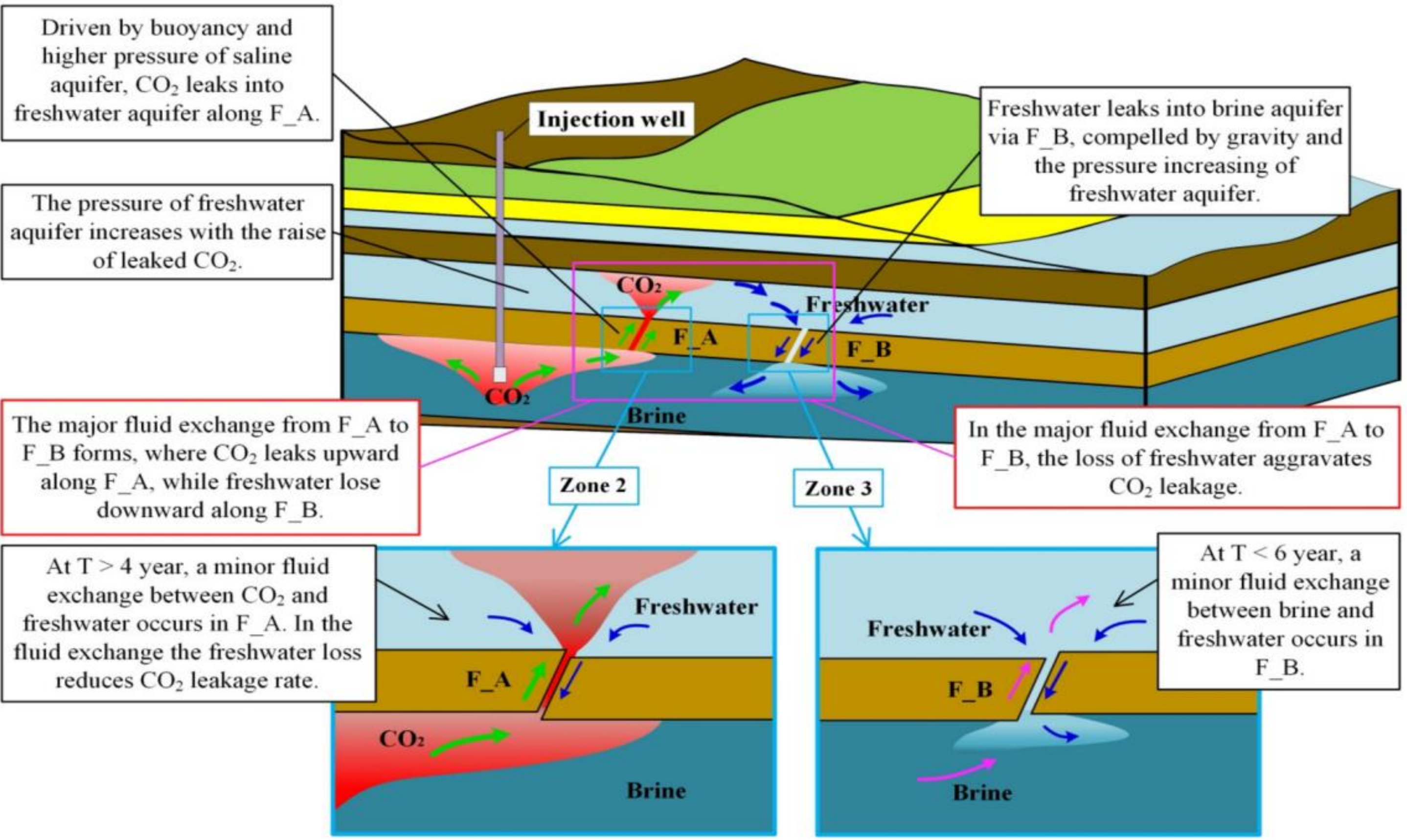
Properties	Values
Rock compressibility (Pa^{-1})	4.5×10^{-10}
Rock grain density (kg/s)	2600
Rock grain specific heat (J/kg °C)	920
Formation heat conductivity (W/m °C)	2.51
λ: index	0.457
S_{lr}: residual liquid saturation	0.3
S_{ls}: maximum liquid saturation	1.0
S_{gr}: residual gas saturation	0.05
P_0: pressure coefficient (kPa)	19.59
Porosity of fault (%)	30
Porosity of freshwater aquifer (%)	15
Porosity of saline aquifer (%)	15
Porosity of caprock (%)	6
Porosity of lower permeability layer (%)	2
Permeability of fault (mD)	590
Permeability of freshwater aquifer (mD)	59
Permeability of saline aquifer (mD)	59
Permeability of caprock (mD)	5.9×10^{-4}
Permeability of lower permeability layer (mD)	5.9×10^{-5}

PRELIMINARY EXPECTATION



The distribution of gas CO_2 saturation (Zhang *et al.* (2018)).

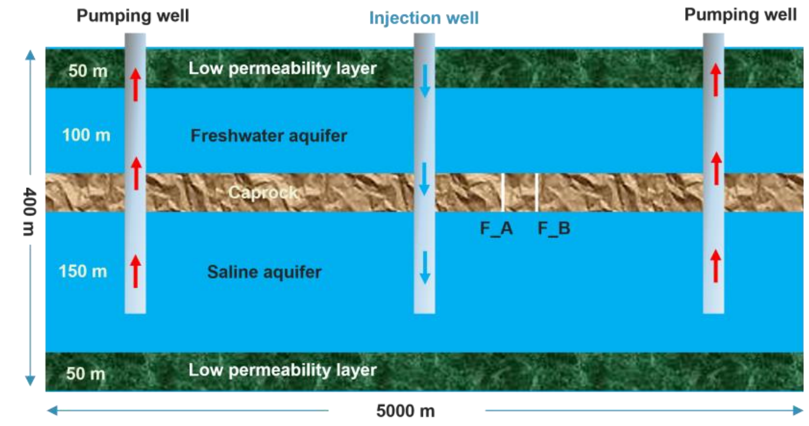
Mechanism of Fluid exchange (Zhang *et al.* (2018)).

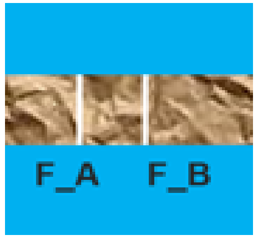


FUTURE WORK

- Validation and consideration of the horizontal flow characteristics of the CO_2 plume.

- Apply faults into caprock layer and simulate CO_2 leakage scenarios.





THANKS FOR YOUR LISTENING!