APEC, 2005

Effectiveness on Cap Rock Mechanical Stability during Carbon Storage in Deep Saline Aquifer

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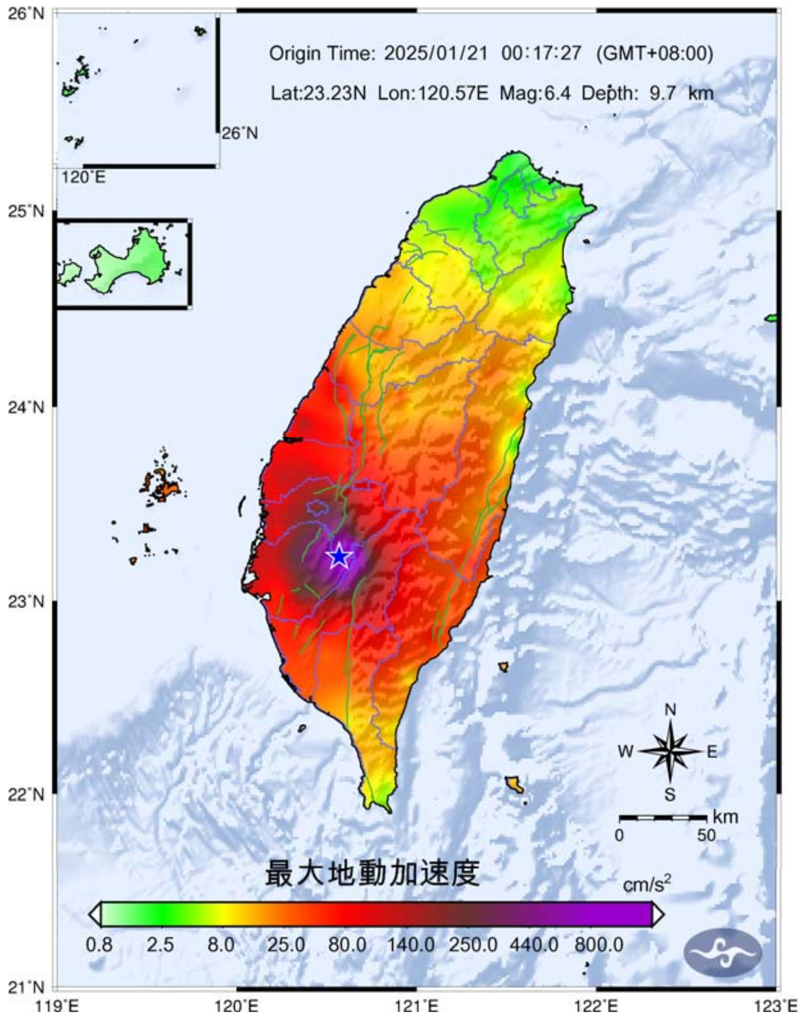
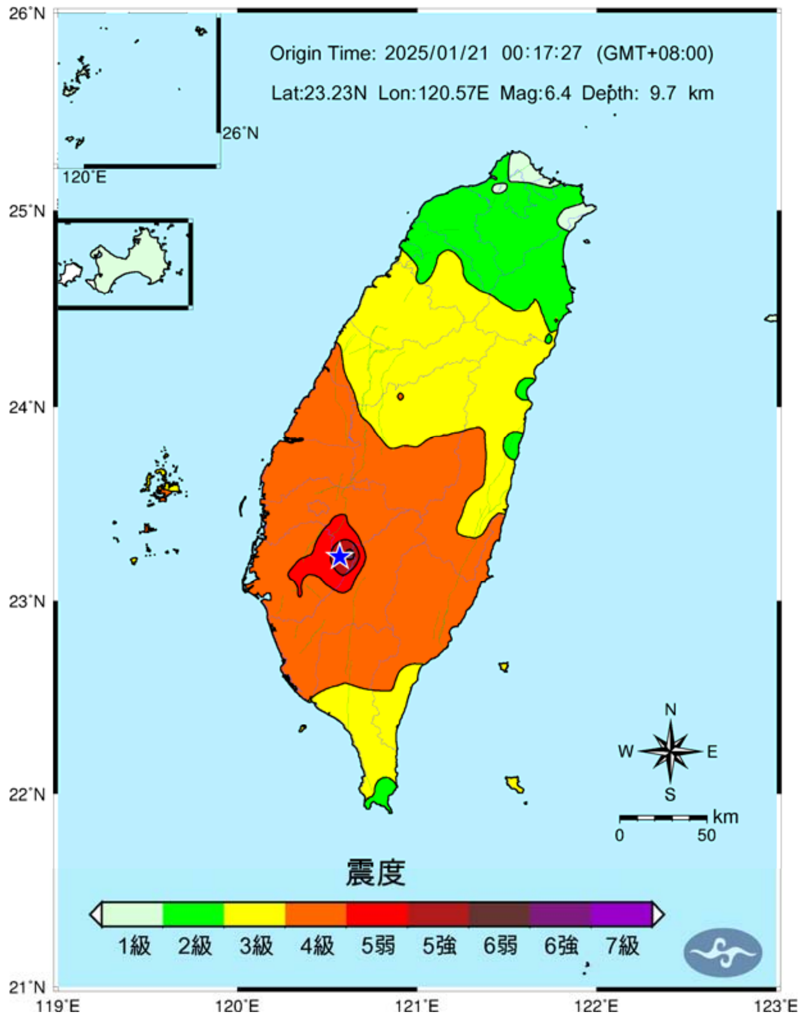
SINOTECH ENGINEERING CONSULTANTS, INC.


00:17
國家級警報
[地震速報 Earthquake Alert]01/21 00:17左右南部地區發生顯著有感地震，慎防強烈搖晃，就近避難「趴下、掩護、穩住」，氣象署。Felt earthquake alert. Keep calm and seek cover nearby. CWA 02_2349 1181 避難宣導：https://gov.tw/KNs
確定

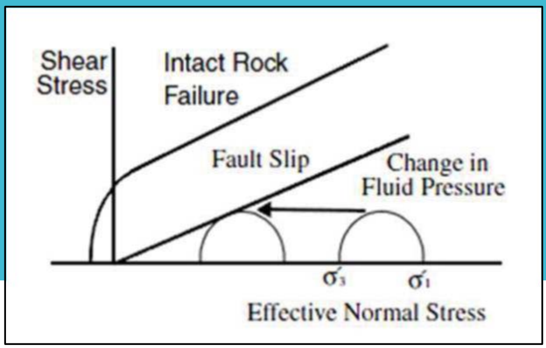

Origin Time: 2025/01/21 00:17:27 (GMT+08:00)
Lat:23.23N Lon:120.57E Mag:6.4 Depth: 9.7 km
最大地動加速度
cm/s²
0.8 2.5 8.0 25.0 80.0 140.0 250.0 440.0 800.0
26°N 25°N 24°N 23°N 22°N 21°N
119°E 120°E 121°E 122°E 123°E
N W E S
km 0 50

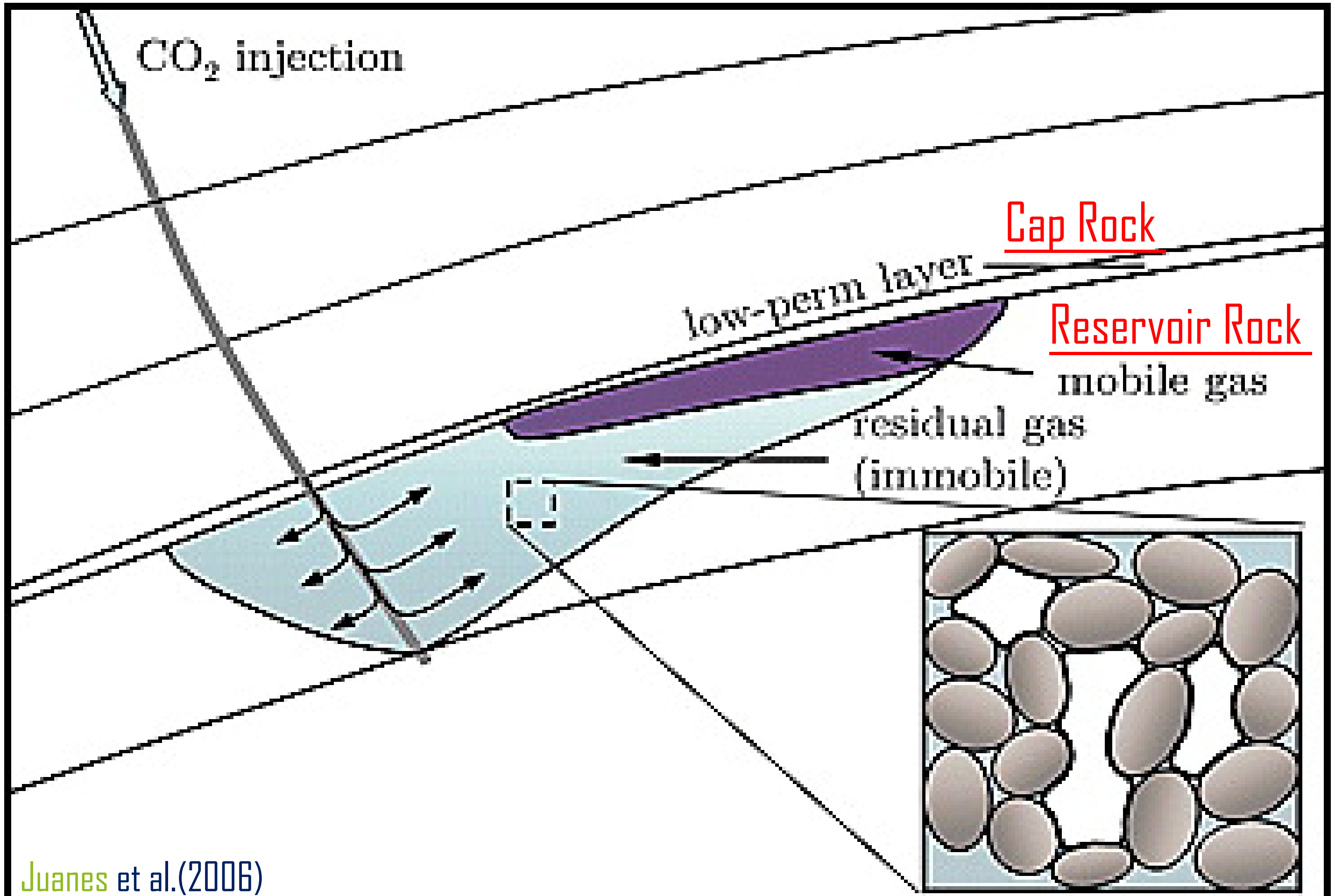

Origin Time: 2025/01/21 00:17:27 (GMT+08:00)
Lat:23.23N Lon:120.57E Mag:6.4 Depth: 9.7 km
震度
1級 2級 3級 4級 5弱 5強 6弱 6強 7級
26°N 25°N 24°N 23°N 22°N 21°N
119°E 120°E 121°E 122°E 123°E
N W E S
km 0 50

Carbon Storage in Deep Saline Aquifer (DSA)

- Cap Rock Should be Impermeable or low-permeable

- Mechanical Stability Should be secured

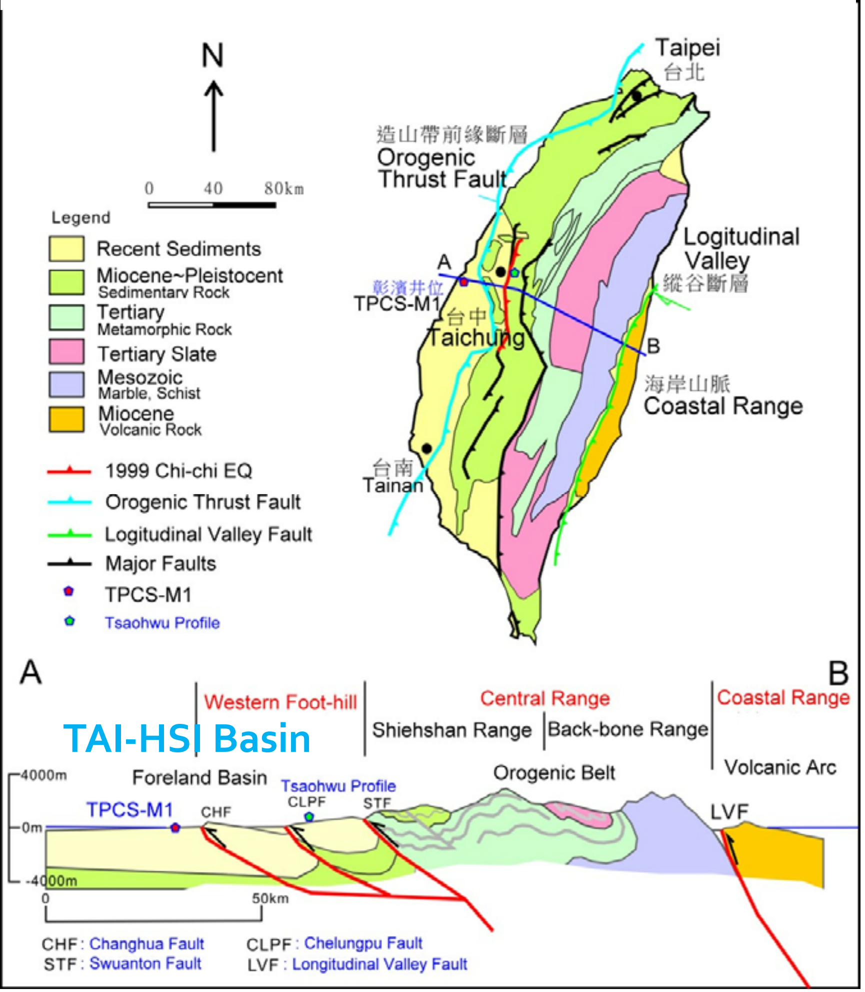




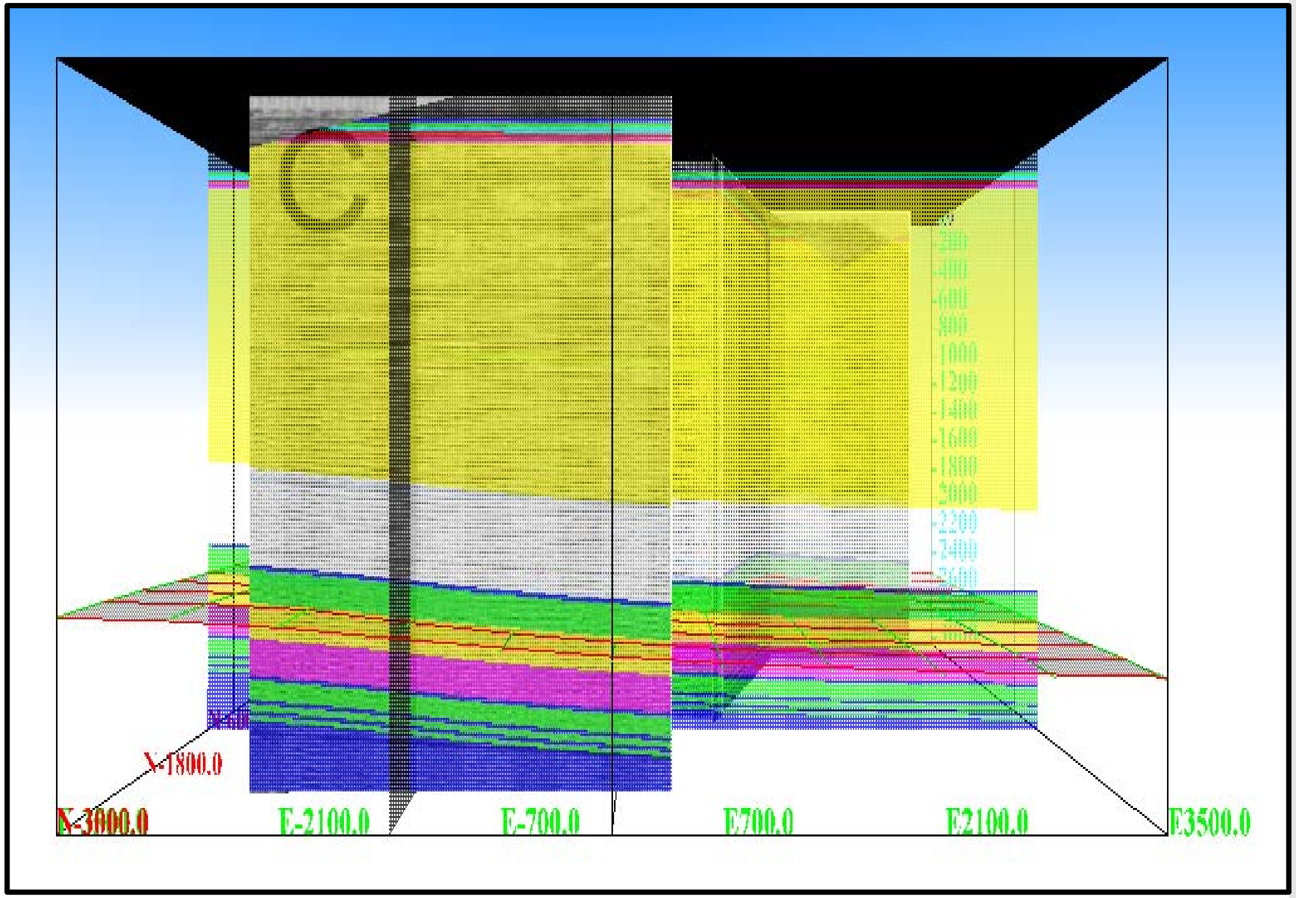
Juanes et al.(2006)

Carbon Storage Opportunity in DSA

Geologic Information Showing the Pilot Site

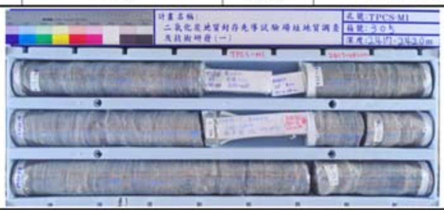


Reflection Seismic Images (2010) Before Pilot Drilling (TPCS-M1)



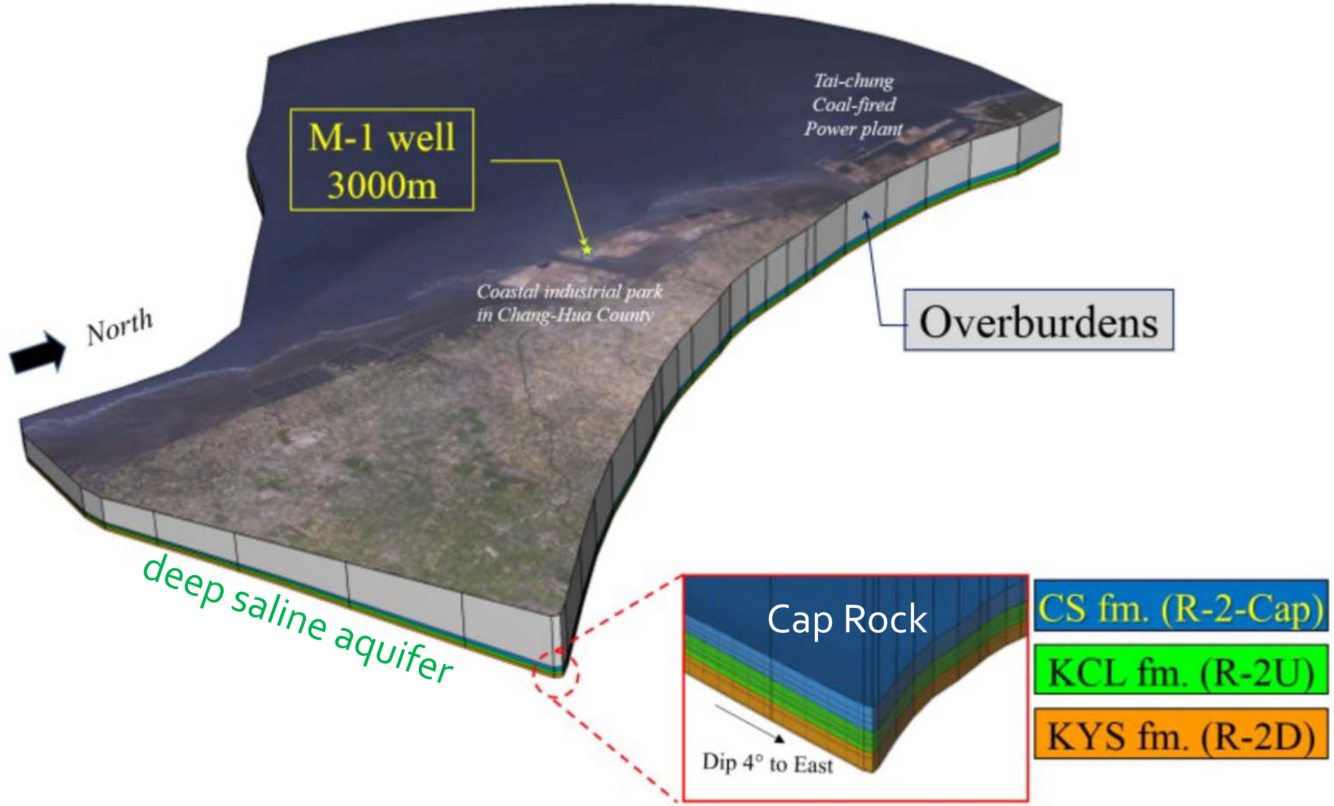
TPCS-M1 Well TVD 3000m, Core length Recovered = 1379m (2012)

計畫名稱：二氧化碳地質封存先導試驗場址地質調查及技術研發(一)			
孔號：TPCS-M1			
箱號	305	深度	2417～2420m



Location of M-1 well and Target Formations for Pilot Study

- **3-D model** of candidate deep saline aquifer
- **M-1 well:** Located in the <u>Changhua Coastal Industrial Park</u>, Chang-Hua County.

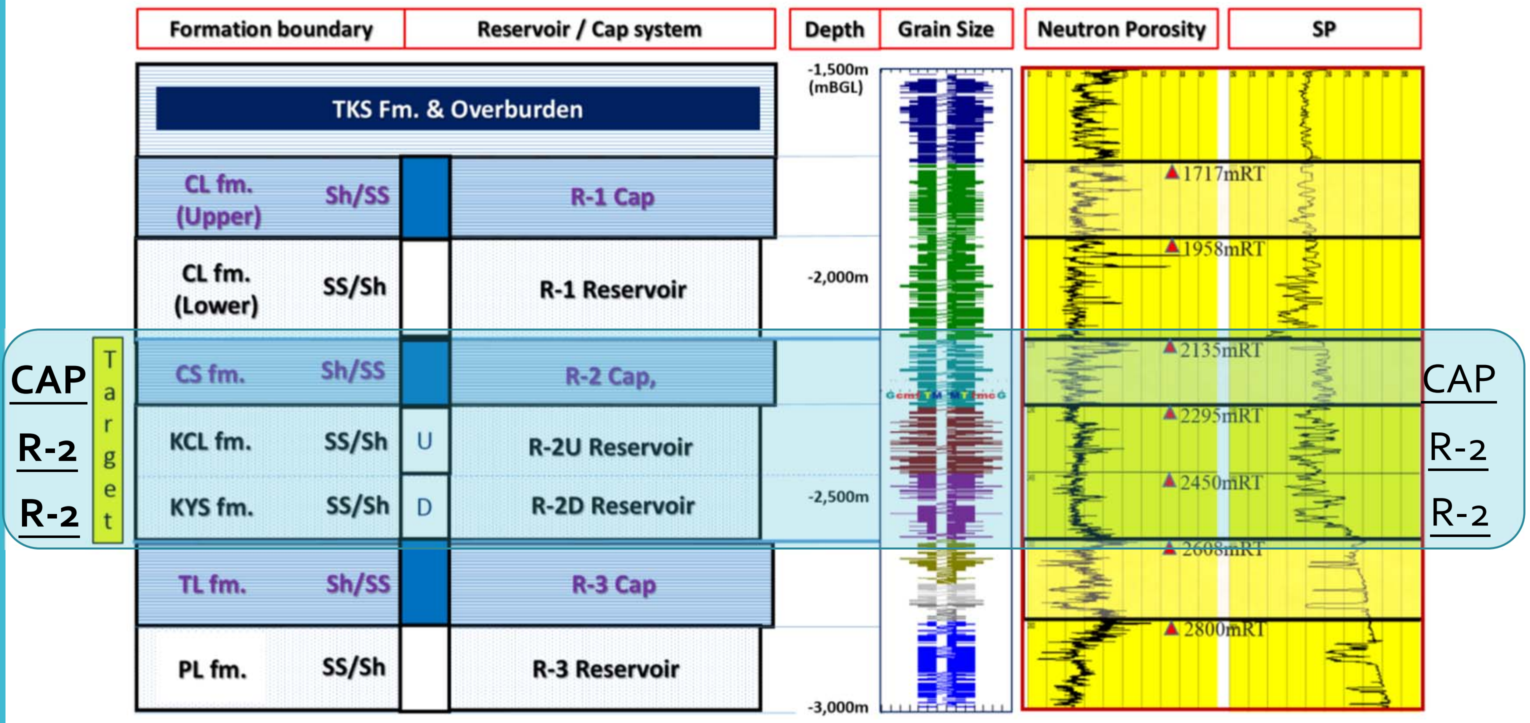


TAI-HSI Basin

R-2 Considered as the Best Reservoir to Develop

The general **geological sequence** of the major storage formations (R-1, R-2, R-3)

from **M-1 well** investigation.



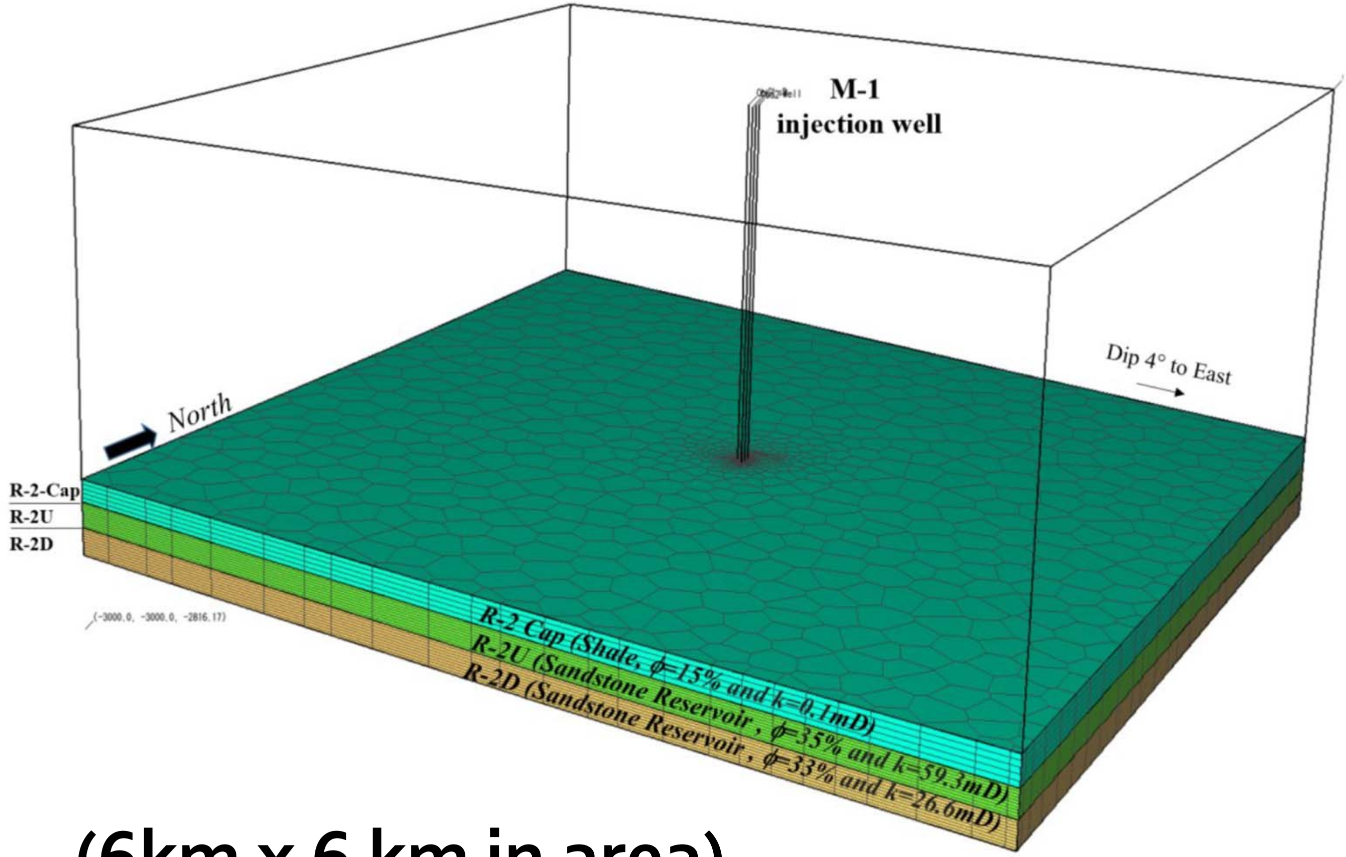
from **M-1 well** investigation

Use TOUGH2-CSM to Perform Simulations Coupling T-H-M.

The 3-D numerical model for **R-2 candidate**

Study of
Cap Rock Mechanical Stability
in deep saline aquifer

TOUGH2-CSM (TOUGH2-Carbon Sequestration Model) (Simulator Provided by LBNL)

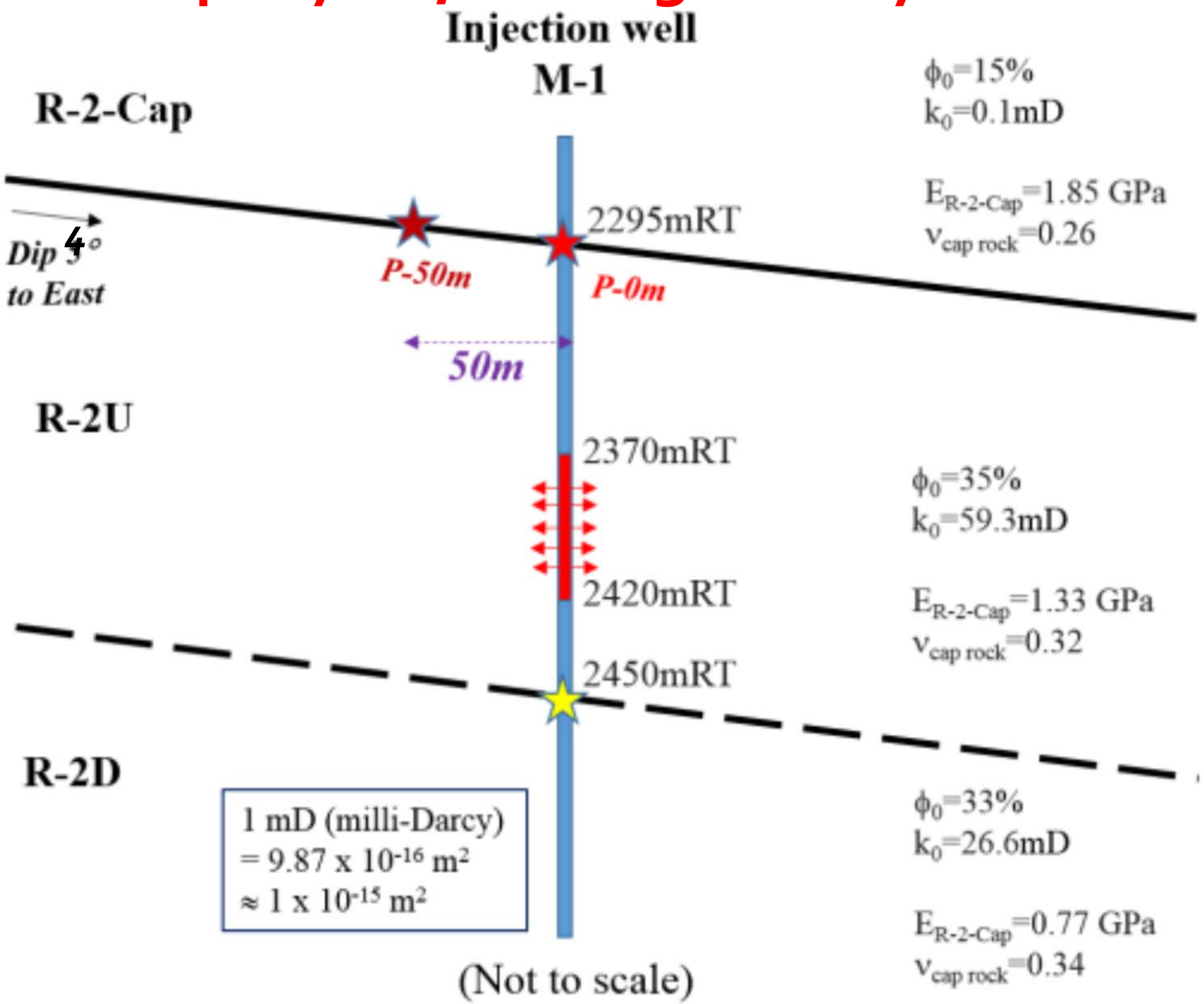


(6km x 6 km in area)

Scenario: Injection 1 Mt CO2 per year, lasting for 20 years

Monitoring zone elements
at bottom of R-2-CAP

At
P-0m
P-50m



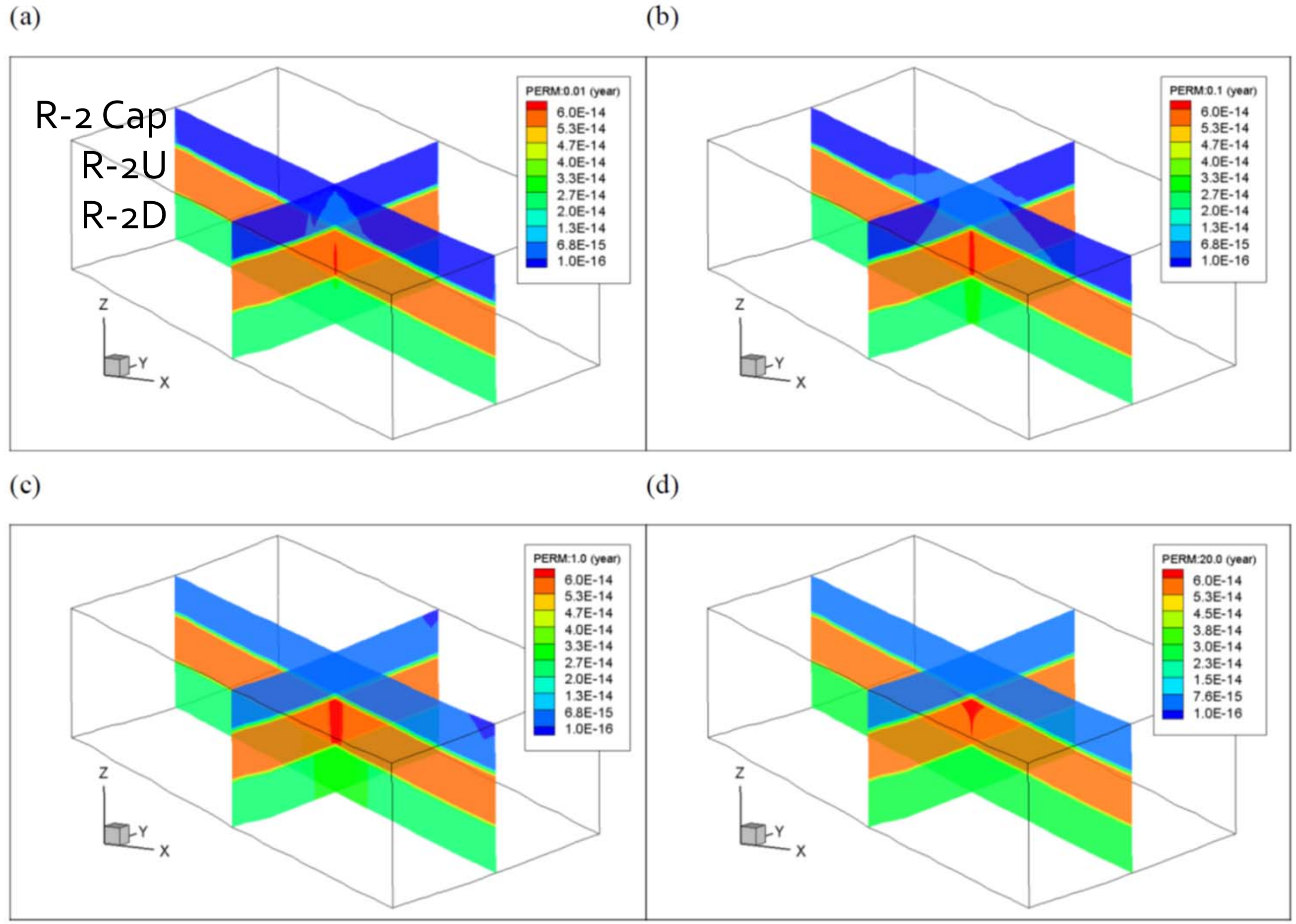
Parametric settings of the T-H-M model.

Initial condition	Boundary condition	Material properties
• Pore pressure (P_w):	• Top : fixed	• T (Thermal) : isothermal
Hydrostatic pressure, $P_w = \rho_w h$	• Bottom : fixed	• H (Hydraulic) :
• Temperature :	• Four sides : fixed, no flow	R-2-Cap: ϕ=15% and k=0.1mD
Top 20°C with 2.5°C /100m gradient		R-2U: ϕ=35% and k=59.3mD
• CO_2 : 0.0		R-2D: ϕ=33% and k=26.6mD
• NaCl : 3%		• M (Mechanical) :
• Overburden pressure (P_{rock}) :		$E_{R\text{-}2\text{-}Cap}$=1.85 GPa; $\nu_{cap\ rock}$=0.26
Lithostatic, $P_{rock} = \rho_{rock} h$		$E_{R\text{-}2U}$=1.33 GPa; $\nu_{R\text{-}2U}$=0.32
		$E_{R\text{-}2D}$=0.77 GPa; $\nu_{R\text{-}2D}$=0.34

P H Winterfeld , Y S Wu (2013), User's guide for TOUGH2-CSM (TOUGH2-Carbon Sequestration Model) -massively parallel simulation of fullycoupled flow with Geomechanics Posted: 2013-01

Highest Over-stressing Risk in Cap Rock in the 1st Year of Injection

- Permeability variations during 20 years of injection in **R-2**:
  (a) at 0.01 year;
  (b) at 0.1 year;
  (c) at 1st year;
  (d) at 20th year.
- The change of permeability (m2) is observed, but is comparatively small



The order of permeability (m2) of the R-2-Cap **gradually increase** from 10^{-16} to 10^{-15} (**dark blue** to pale blue in the plots)

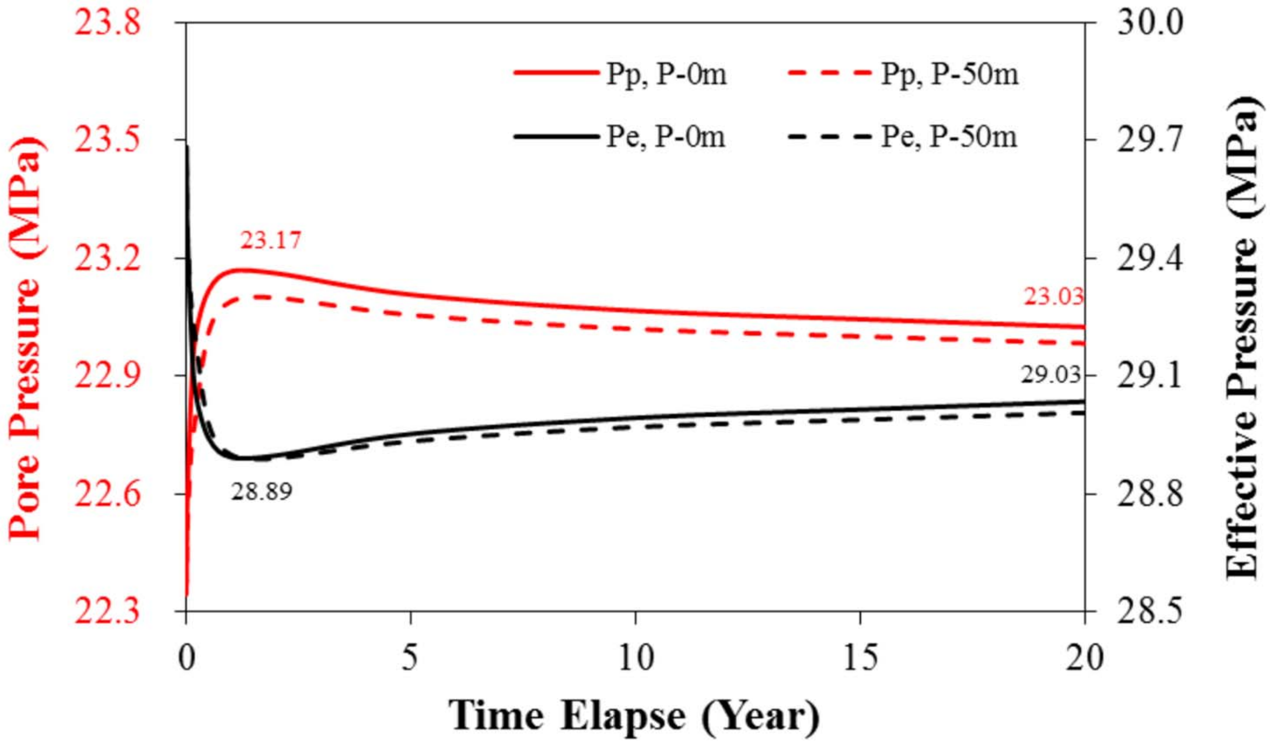
Evolution of pore pressures and effective stresses in cap rock.

At the end of 20-year injection,

- the increased amount of the pore pressure (Pp) in P-0m pore pressure is only 3.9%.
- Effective stresses (Pe) shows only 1.7% of maximum change in P-0m

➢ Only minor impact to the cap rock

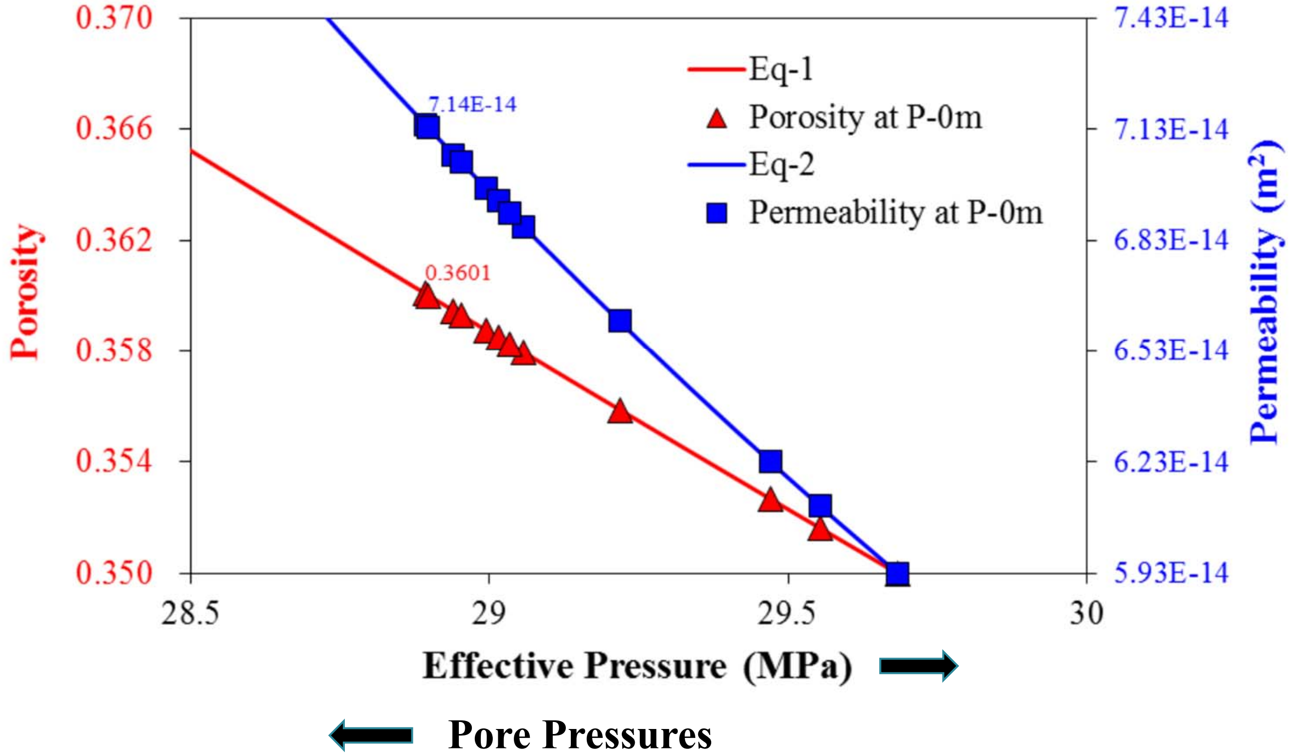
➢ The risk of causing the rock failure is low



Variations of Porosity and Permeability with Effective Pressure

During the 20-year injection period, at P-om

- The **negative correlations** of porosity and permeability with coherent effective stress



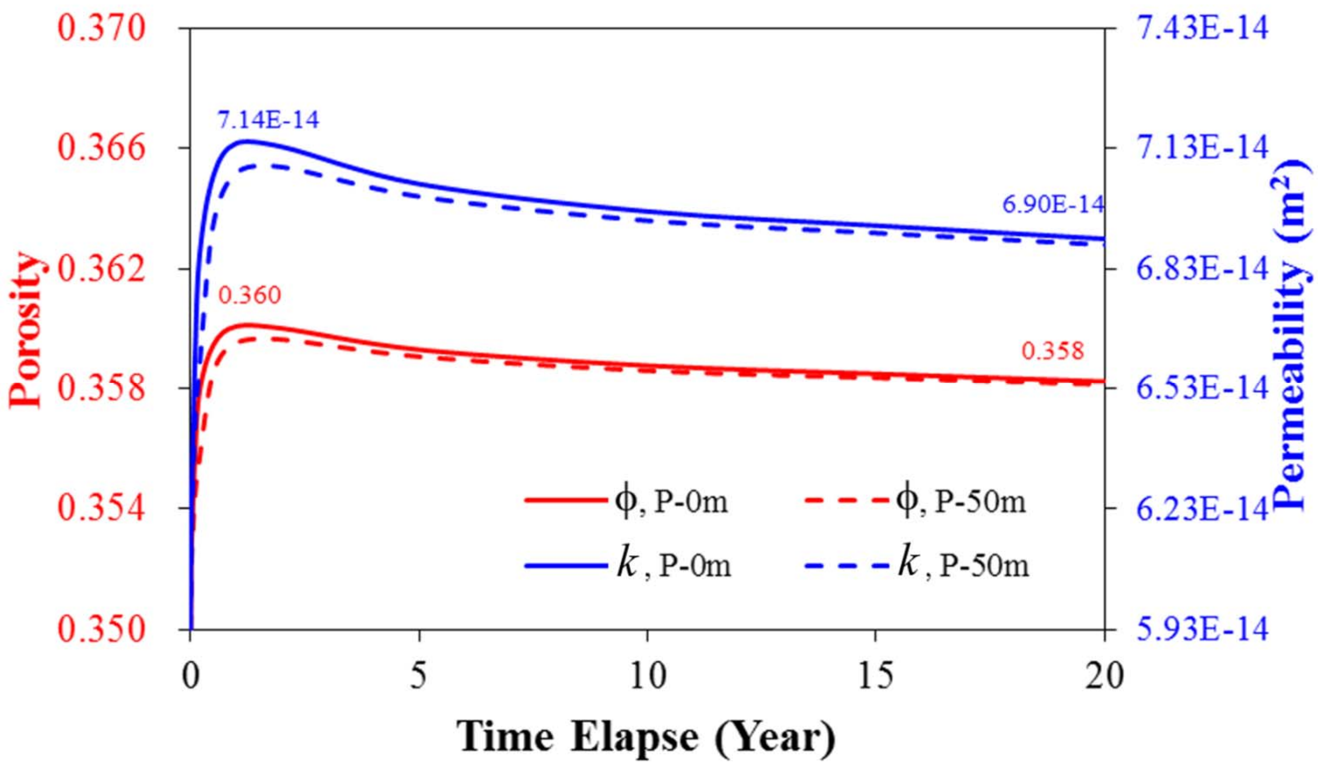
$$\phi = \phi_r + (\phi_0 - \phi_r)e^{-a\sigma'}$$ Eq-1 Rutqvist et al. (2002)

$$k = k_0 e^{c(\phi/\phi_0 - 1)}$$ Eq-2

Evolution Changes of Porosity and Permeability Under the Cap Rock

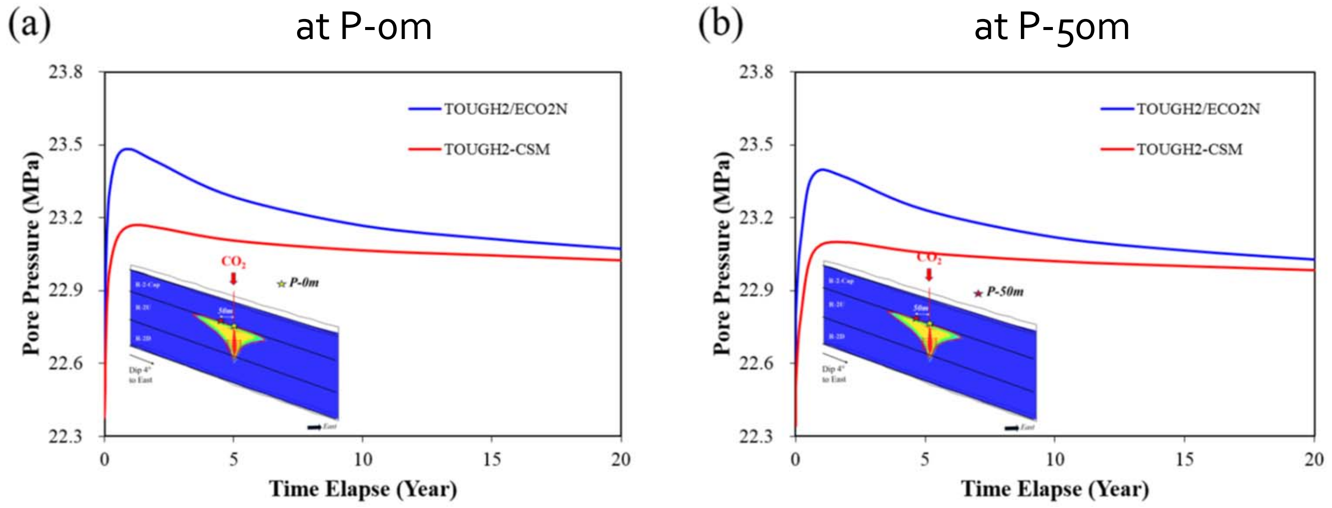
During the 20-year injection period, at P-0m

- The maximum change of zone **porosity** is about 2.86%.
- the maximum change in zone **permeability** is about 20.4%.



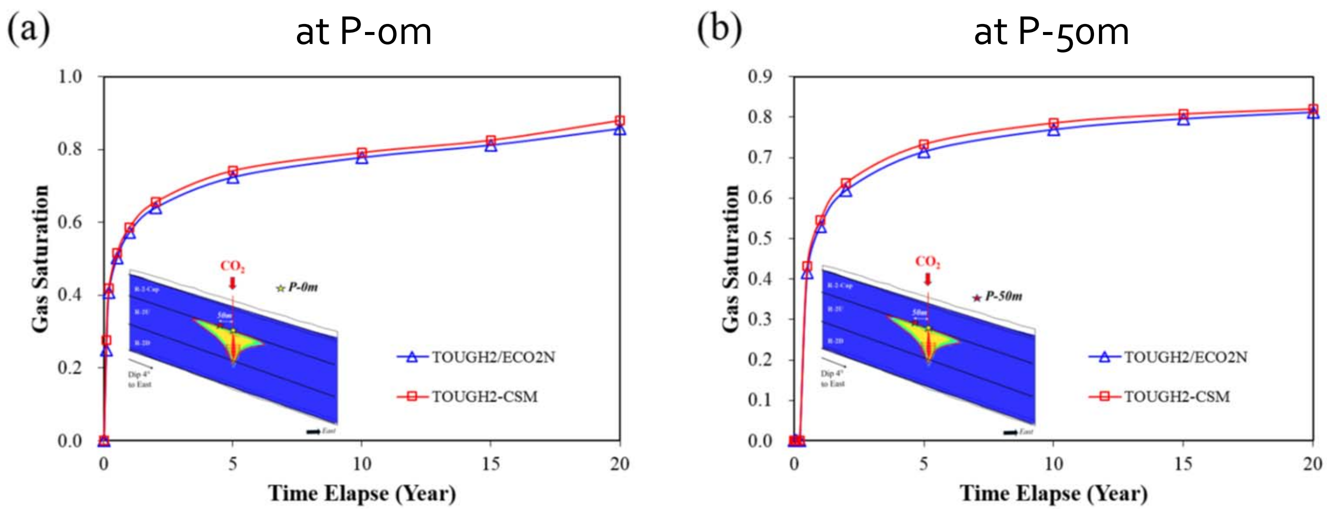
Evolutions of Pore Pressure Under the Cap Rock w/o T-H-M

Using the TOUGH2/ECO2N might over-exaggerate the induced **pore pressure** during the CO2 injection where substantially no deformation of pore space were assumed.



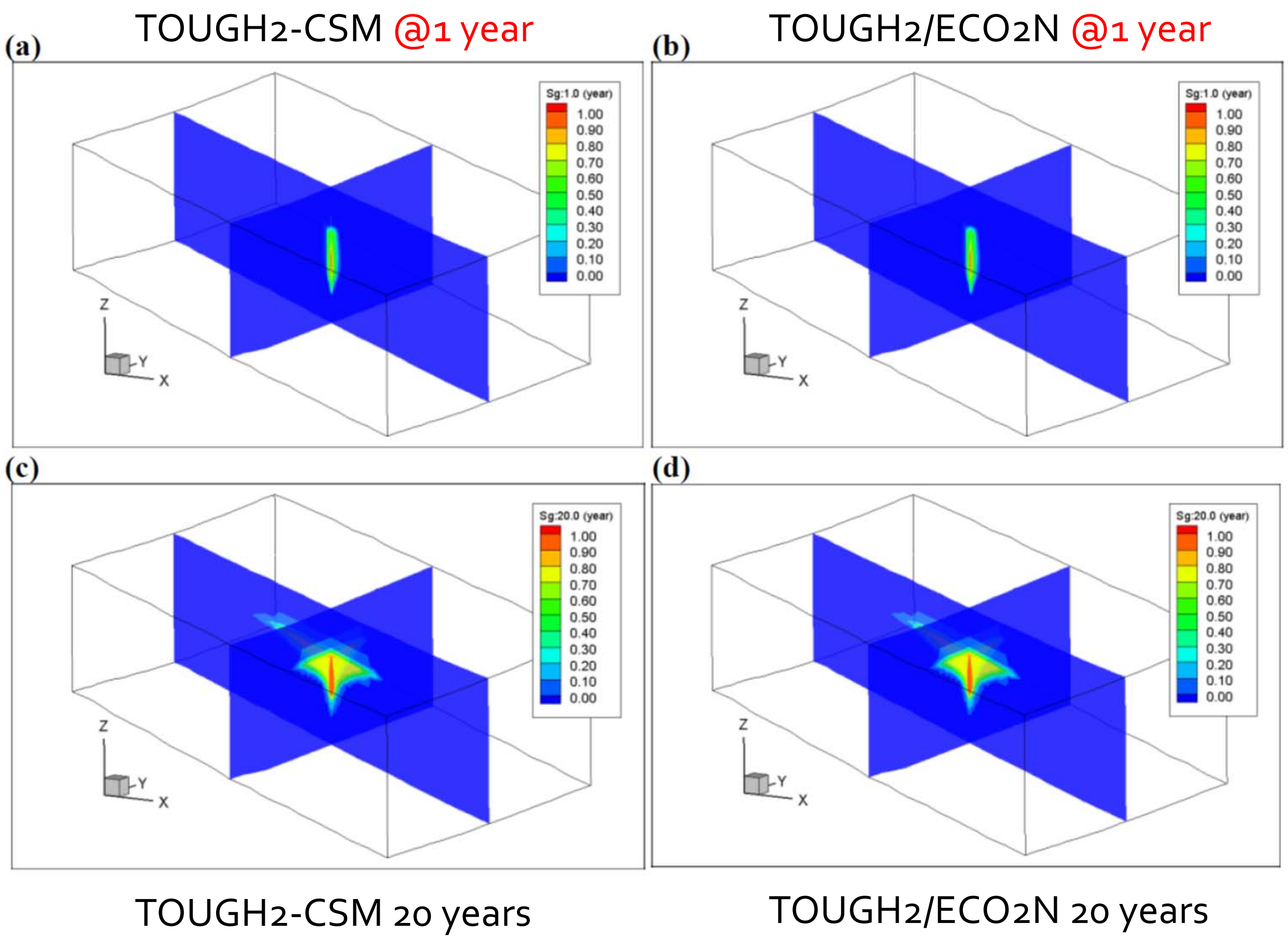
Evolutions of Gas Saturation under the cap rock w/o T-H-M

In a contrast, comparison results on **gas saturation** revolution of CO2 are almost identical using both codes



Comparison of Gas Saturation by TOUGH2-CSM and TOUGH2/ECO2N

- The **mechanical coupling** did not cause significant change on the **gas saturation** during the CO_2 plume migration process.



Conclusions

- **TOUGH2-CSM** can predict the change of porosity, permeability, pore pressure, and effective stress for cap rock (R2-CAP) during 20-year CO2 injection with M-1 injection scenario.
- By scenario analysis, the increasing porosity and permeability with the increased pore pressure during CO2 injection may release the tension to endanger the cap rock stability and reduce the risk of causing the cap rock failure.
- **Effective stress** simulated here were only representing the **linear elastic stress-strain behavior**, without considering material damage of the formation rock.
- Simulation results of **TOUGH2-CSM** code exhibited **lower** induced pore pressure values at injection affected zones than those by using **TOUGH2/ECO2N**
- Modelling results can serve as **a communicating material to obtain public acceptance** regarding cap rock mechanical stability during carbon storage in deep saline aquifer

Thank You

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