Evaluation of long-term stability of caprock sealing under deep saline CO_2 sequestration environment

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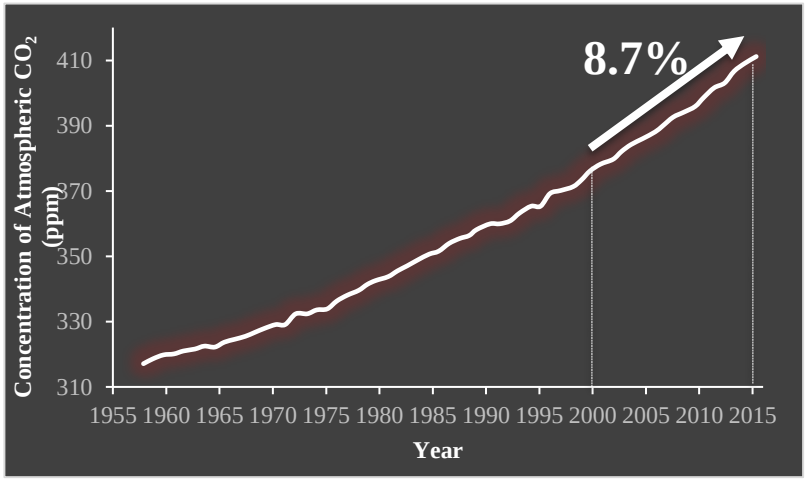
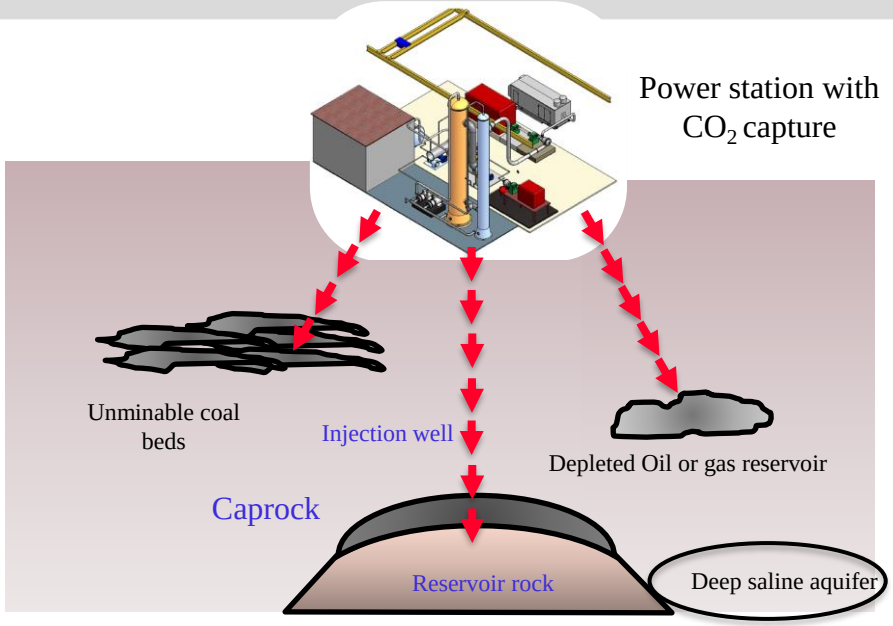
Presentation Outline

- Introduction
- Research objectives
- Research methodology
- Research findings

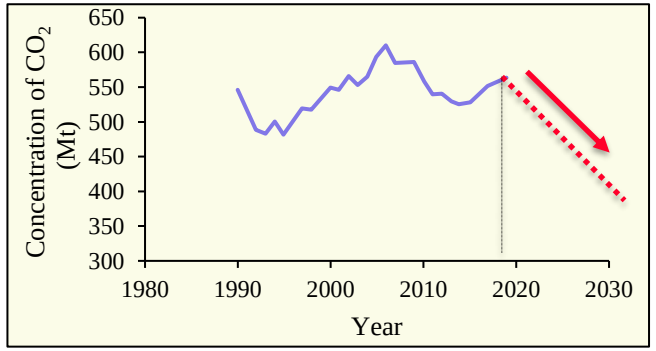
Introduction

Deep saline aquifers for CO_2 sequestration

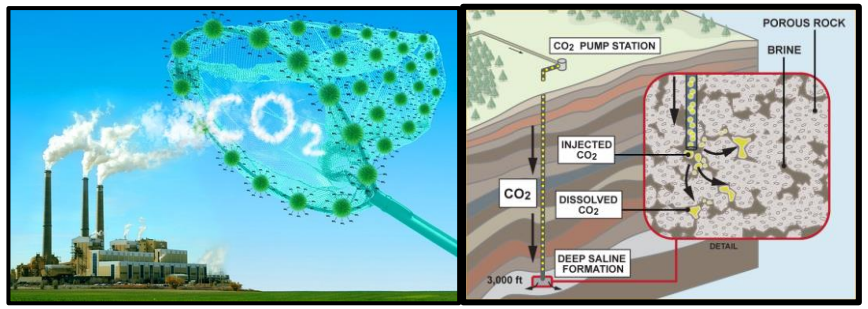




Mitigation Measures to reduce CO_2 emissions → **Carbon Capture and Storage** (CCS) technique



Australia CO_2 emission
(Department of Environment and energy, 2016)



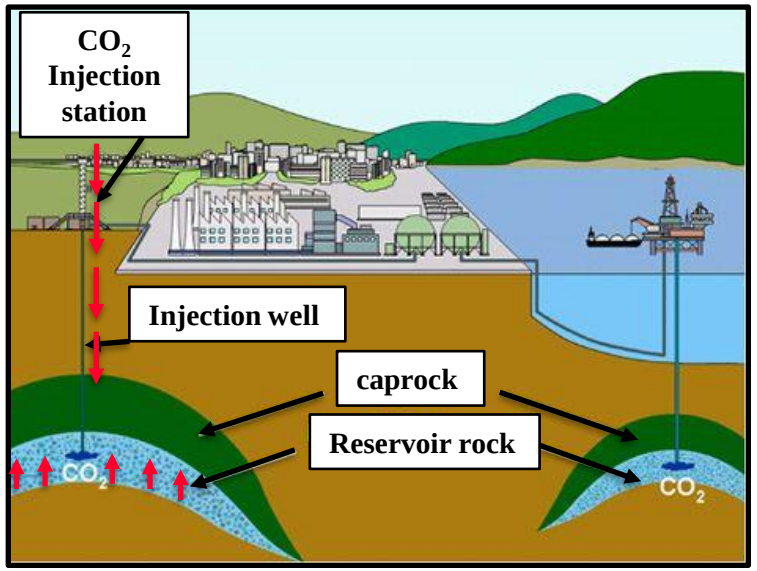
(http://revolution-green.com/category/carbom/carbon/) http://www.fossiltransition.org/pages/carbon_storage_and_sequestration/30.php

Therefore, it is crucial to develop deep saline CO_2 sequestration projects close to industrial centers.

Introduction

CO_2 sequestration in deep saline aquifers

- CO_2 is injected into the reservoir rock through injection well
- Reservoir rock is a permeable rock made up of sandstone filled with brine (mixture of ion + water)
- Depth of aquifer > 800 m. Aquifer properties - Temperature > 31.1°C and Pressure > 7.39 MPa. So, injected CO_2 remains in supercritical phase
- $ScCO_2$ density and viscosity < brine density and viscosity. So CO_2 tries to move upward direction. It is prevented by caprock- impermeable seal made up of shale, mudstone, siltstone or claystone. The specialty of caprock is the presence of a lot of clay minerals (Kaolin, Smectite, Illite, and Chlorite).



CO_2 sequestration in deep saline aquifers
(Source:http://www.captureready.com/userfiles/image/Carbon%20Storage/Carbon%20Storage_RITE.jpg)

Why caprock is important?

- Prevent back-migration of injected $ScCO_2$
- Prevent ground heave (uplift)
- Avoid contamination of CO_2 with fresh underground water
- Avoid seismic events
- Contribute to mineral trapping

Although the whole CO_2 storage permanence depends on caprock integrity, the knowledge regarding its behavior in long term is still a question.

Research Aim

Aim: Investigation of caprock chemical reactivity under CO_2 sequestration environment in long-term.

- To find the reactivity of caprocks in the presence of CO_2 in laboratory scale
- To estimate the long-term reactions
- To estimate the porosity changes along caprock height

Comparison of reactivity

Mudstone

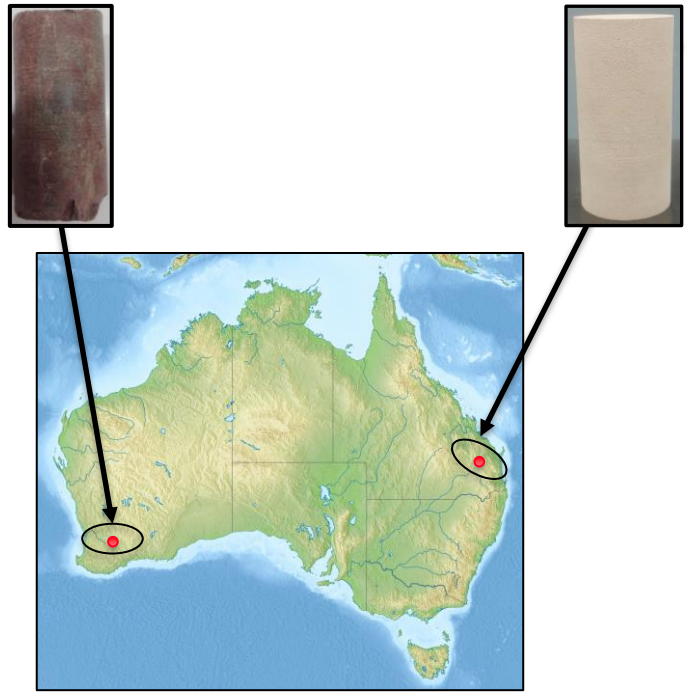
Harvey 2 well, South-west Hub geo-sequestration Project, Perth (real caprock)

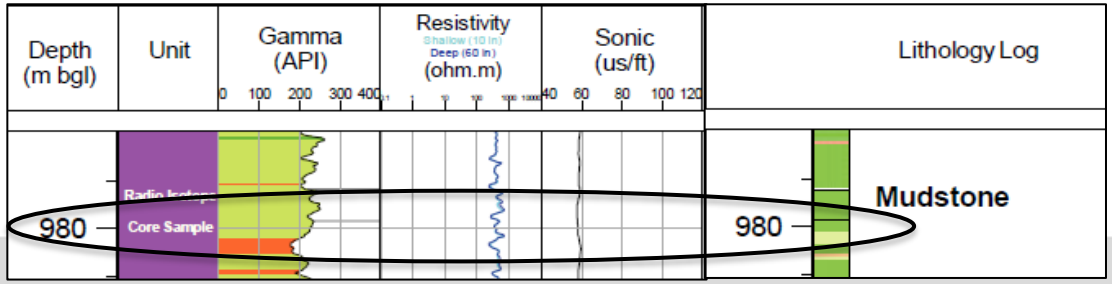
Mineral	Composition (%)
Quartz	32
Goethite	6
Orthoclase	9
Illite	20
Kaolinite	6
Chlorite	13
Plagioclase	12
Other minerals (pyrite and montmorillonite)	2

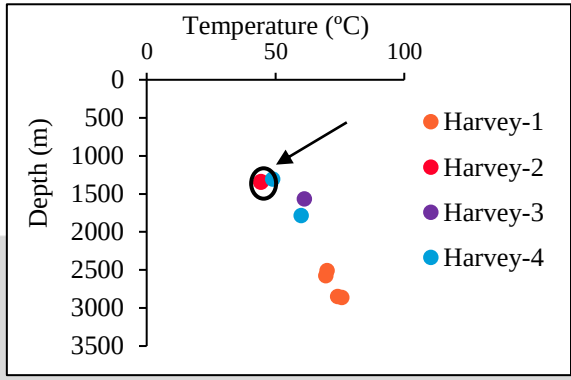
Siltstone

Eidsvold formation in QLD (as a representation of caprock)

Mineral	Composition (%)
Quartz	36
muscovite	7
Kaolinite	53
Other minerals (pyrite and montmorillonite)	4







Research Methodology

Comparison of reactivity

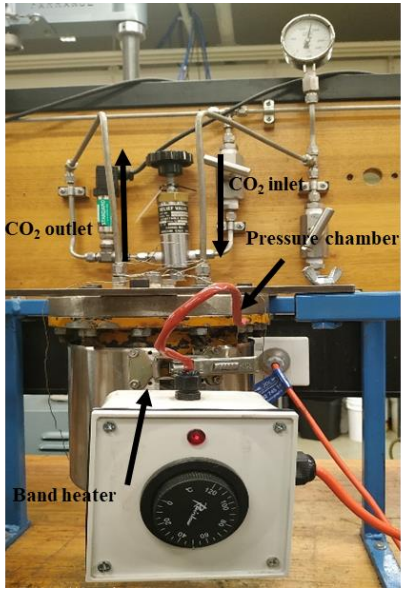
Mudstone → Laboratory batch experiments

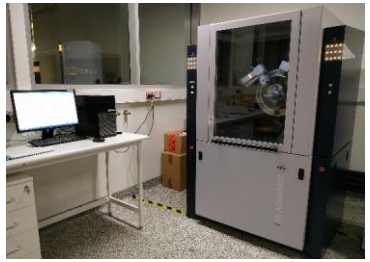
Siltstone → Laboratory batch experiments

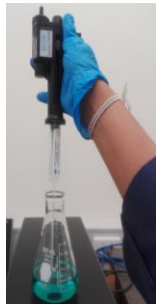
To find chemico-mineralogical alterations due to CO_2 injection in laboratory scale

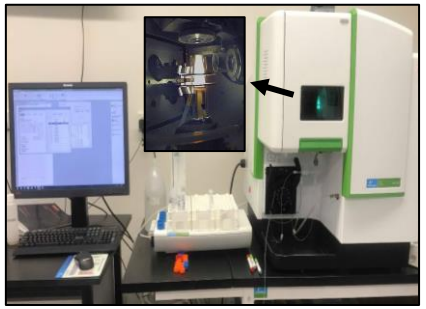
Provides the actual reservoir condition
- Salinity 4.5%
- Pressure 10MPa
- Temperature 40 °C for 37 weeks

To increase reactivity
- Crushed caprock samples (75-425 µm) were used









- Mudstone – Kaolinite, anorthite, chlorite and orthoclase mineral dissolution
- Mudstone - Kaolinization, precipitation of amorphous silica, gibbsite and Fe bearing colloids
- Siltstone - Kaolinite, anorthite and muscovite dissolution
- Quartz is a stable mineral in both caprocks
- Dissolution is significant in both types of caprocks.

Research Findings

Comparison of reactivity

Mudstone → Laboratory batch experiments → Kinetic batch modelling

Siltstone → Laboratory batch experiments → Kinetic batch modelling

Validate using laboratory experiments and predict long-term chemico-mineralogical changes due to CO_2 injection

- 10 year – Precipitation of gibbsite, kaolinite and amorphous silica
- 100 years - Precipitation of pyrophyllite, beidellite and calcite
- 1000 years – Precipitation of clinoptilolite mineral
- 5000 years - Precipitation of montmorillonite, equilibrium of kaolinite and k-feldspar

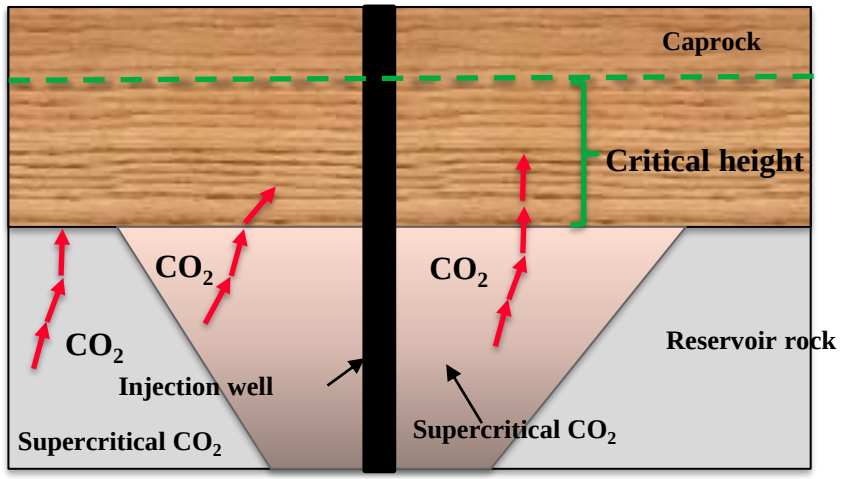
- 10 years – Precipitation of beidellite clay and mordenite minerals
- 1000 years - Precipitation of dawsonite

Research Findings

Comparison of reactivity

Mudstone → Laboratory batch experiments → Kinetic batch modelling → Transport modelling

Siltstone → Laboratory batch experiments → Kinetic batch modelling → Transport modelling



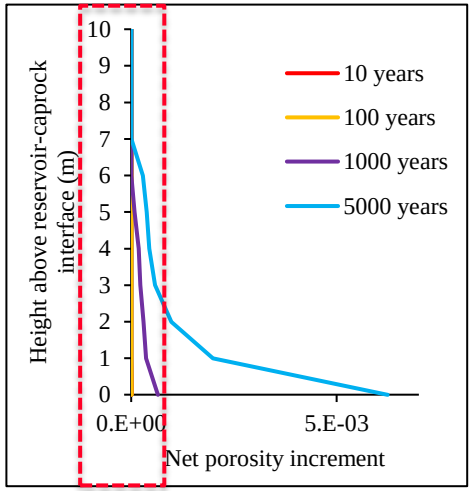
To find porosity changes along the caprock height

- Low porosity increment of the caprock
- Low critical height of the caprock → CO_2 attacking height along caprock

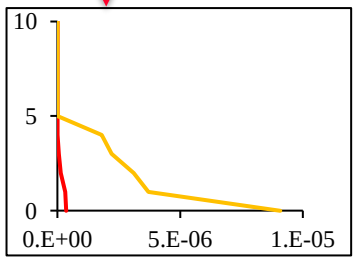
Research Findings

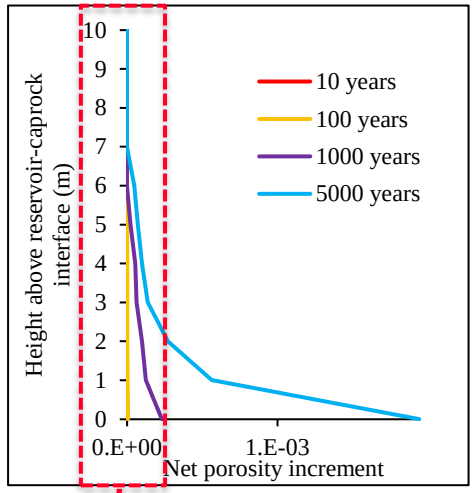
Transport modelling of mudstone

Diffusion

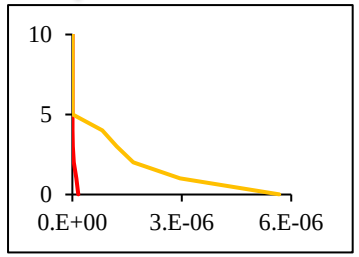


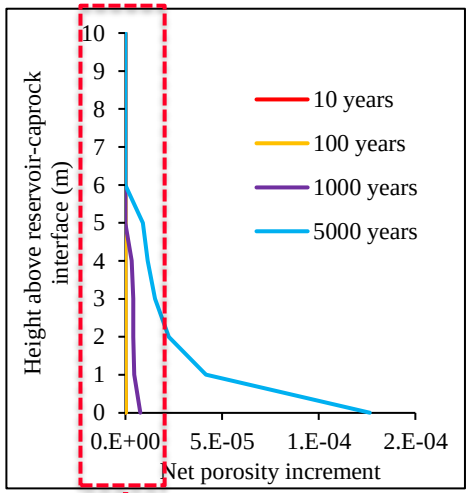
2μm for clay
63 μm for other minerals



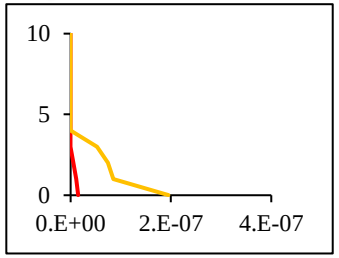


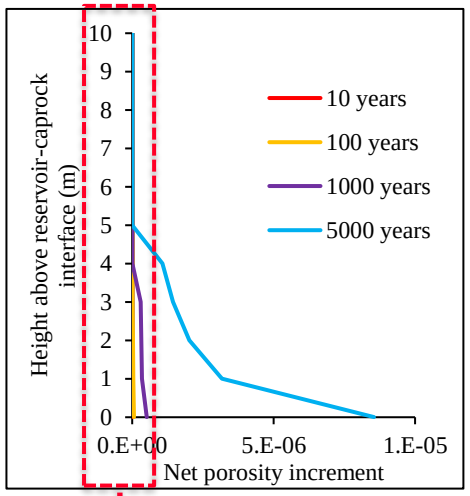
4 μm for clay
126 μm for other minerals



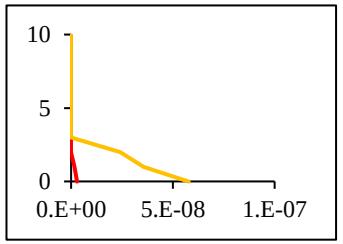


12 μm for clay
378 μm for other minerals





48 μm for clay
1512 μm for other minerals

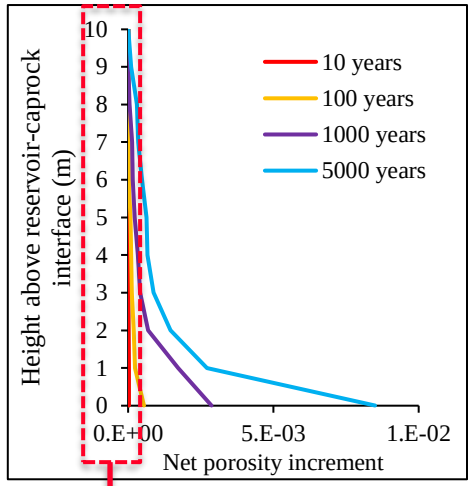


- The critical height of mudstone runs up to 7 m over 5000 years of reaction time

Research Findings

Transport modelling of siltstone

Diffusion



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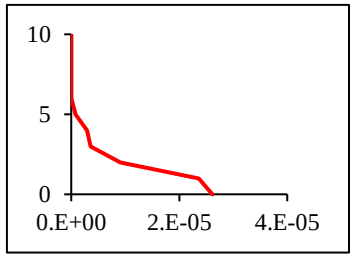

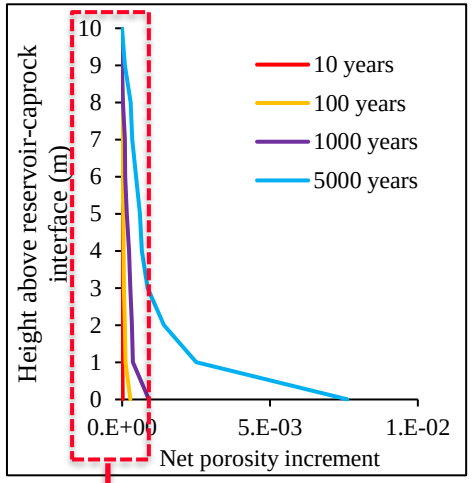

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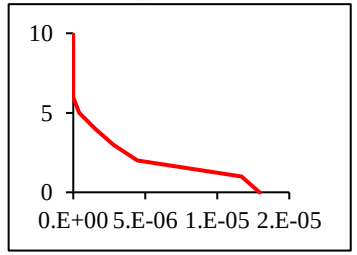

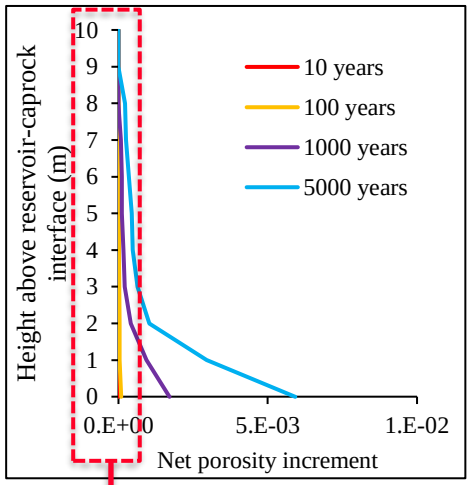

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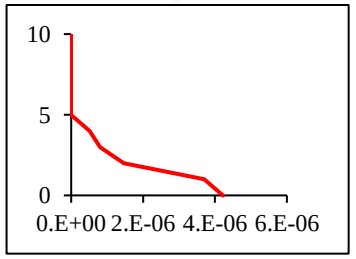

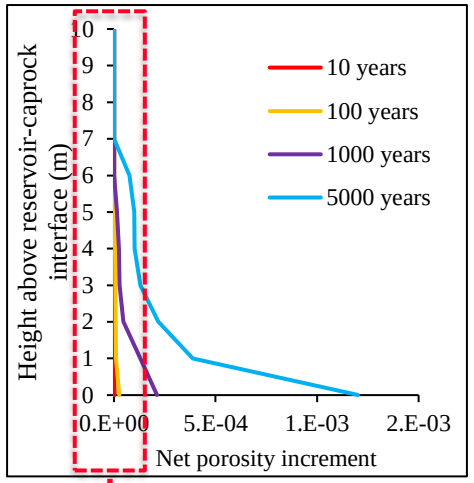

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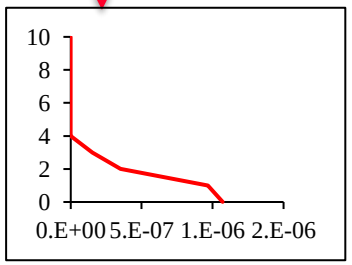

- The critical height of siltstone runs up to 9 m over 5000 years of reaction time

- Based on lower critical heights and net porosity increments, the most suitable caprock is mudstone compared to siltstone
- Stored CO_2 migrates to 9 m after 5,000 years which cannot be neglected

Research Findings

Overall research findings

Caprock reactivity under CO_2 sequestration environment

1. Fastest geo-chemical reactivity in the caprock can be seen during CO_2 injection period and then the mineral reactivity reduces with the CO_2 storage time.
2. Although the primary mineral dissolutions are significant in the caprock in short-term, secondary mineral precipitations such as clinoptilolite, pyrophyllite and beidellite are observed in long-run.
3. The critical depth of siltstone runs up to 9 m which is less that of mudstone. Therefore, mudstone can be considered as a favorable caprock sealing for safe CO_2 sequestration.
4. CO_2 migrates via mudstone caprock with 7 m thickness over 5,000 years while that of siltstone for 9 m.

- Primary mineral dissolutions are dominant in the caprock in short-term due to CO_2 injection. But secondary mineral precipitations appear in long-run.
- Mudstone can be considered as a favorable caprock sealing for safe CO_2 sequestration compared to siltstone
- Coupled effect of diffusion and geochemical reactions cannot be neglected during evaluation over geological timescale

Publications

- **Jayasekara, D.W.**, Ranjith, P.G., Wanniarachchi, W.A.M. and Rathnaweera, T.D., 2020. Understanding the chemico-mineralogical changes of caprock sealing in deep saline CO_2 sequestration environments: A review study. **The Journal of Supercritical Fluids**, p.104819.
- **Jayasekara, D.W**., Ranjith, P.G., Wanniarachchi, W.A.M., Rathnaweera, T.D. and Van Gent, D., 2020. CO_2-brine-caprock interaction: Reactivity experiments on mudstone caprock of South-west Hub geo-sequestration project. **Journal of Petroleum Science and Engineering**, p.107011.
- **Jayasekara, D.W.,** Ranjith, P.G., Wanniarachchi, W.A.M., Rathnaweera, T.D. and Chaudhuri, A., 2020. Effect of salinity on supercritical CO_2 permeability of caprock in deep saline aquifers: An experimental study. **Energy**, 191, p.116486.
- **Jayasekara, D.W.** and Ranjith, P.G.,2020. Effect of Geochemical Characteristics on Caprock Performance in Deep Saline Aquifers. **Energy & fuels** (Invited paper).

THANK YOU