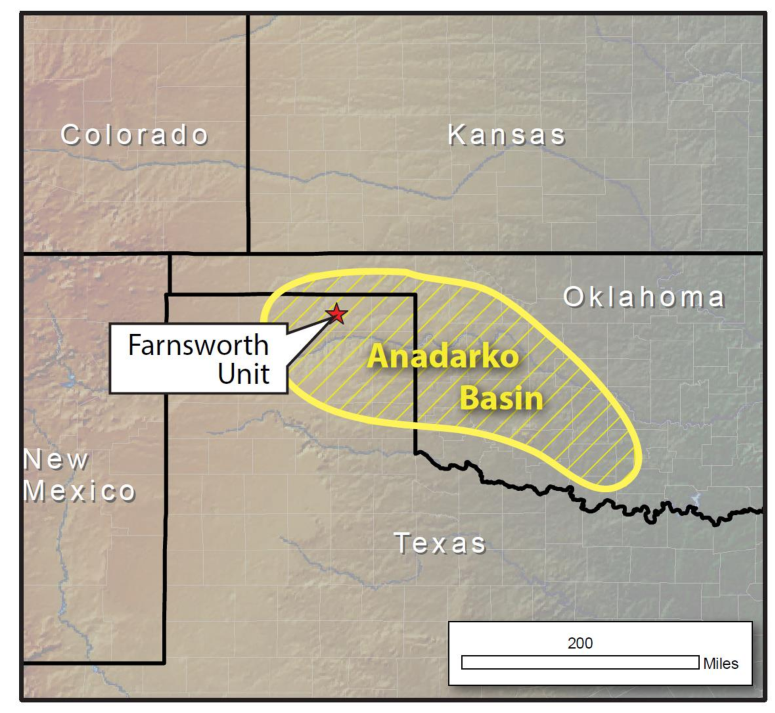
Reactive Transport Modeling of CO_2-Cement-Rock Interactions at The Well-Caprock-Reservoir Interface: A Case Study of The Farnsworth Unit CO_2-EOR Demonstration

Ting Xiao, **Brian McPherson***, Rich Esser, Wei Jia, Amanda Bordelon

Abstract

Wellbore integrity is a key risk factor for geological CO_2 storage. The primary objective of this study is wellbore integrity, and specifically to gain a better understanding of potential impacts of CO_2 leakage through wellbore cement and surrounding caprock. Our primary tool is reactive transport model simulations, calibrated with field data from a case study example, the Farnsworth CO_2 enhanced oil recovery (EOR) unit (FWU) in the northern Anadarko Basin in Texas. Specific objectives include: (1) to analyze impacts on wellbore integrity under CO_2-rich conditions within an operational time scale; and (2) to predict mechanisms of chemical reactions associated with cement-CO_2-brine interactions.

Simulation results suggest that the wellbore cement could maintain its structure and integrity after 100 years. However, pre-existing fractures in the cement-caprock interface are problematic, because calcite in a limestone caprock fracture specifically would dissolve and increase fracture size and permeability.

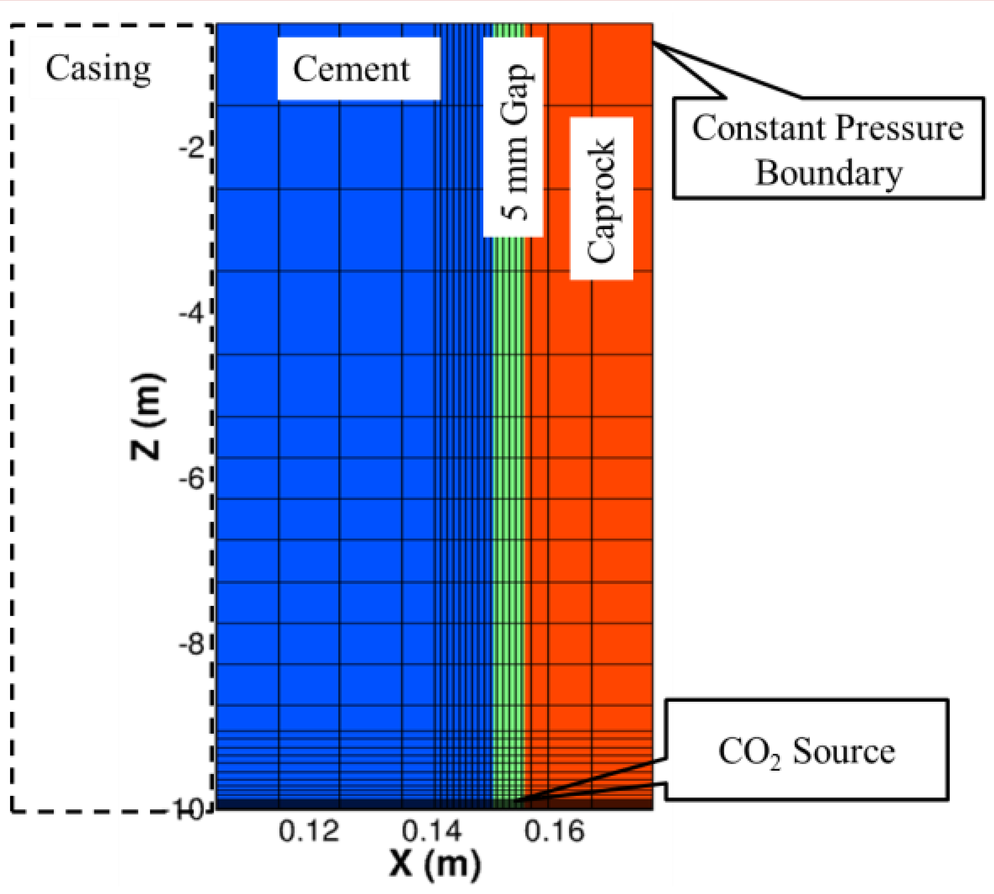


Case study site – The Farnsworth Unit

- An active CO_2-EOR field since 2010
- Southwest Regional Partnership on Carbon Sequestration (SWP) Phase III
- 1 million tonnes of net CO_2 injection through 2017

Modeling Approach

- **Simulation tool**: TOUGHREACT V2 (Xu et al., 2012) ECO2N (Pruess, 2005)
- **2-D radial model**: 874 grids
- **Temperature**: 70 °C
- **Permeability**: $P_{cement} = 10^{-17}$ m^2; $P_{frature} = 10^{-13}$ m^2; $P_{caprock} = 10^{-17}$ m^2
- **Porosity**: $\phi_{cement} = 0.3$; $\phi_{fracture} = 0.7$; $\phi_{caprock} = 0.02$
- **Depth**: ~2300 m
- **Simulation time**: 100 years



Geochemical Settings

- **Cement carbonation**

Time / pH decrease

$$CO_{2(aq)} + H_2O \longrightarrow HCO_3^- + H^+$$

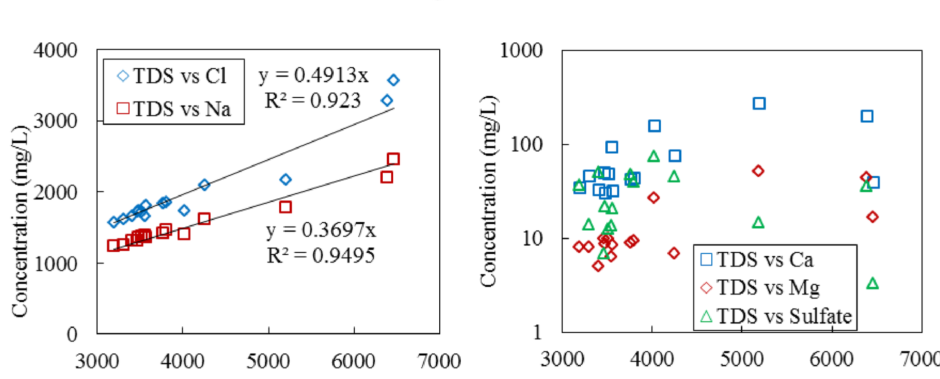
$$Ca(OH)_{2(s)} \longrightarrow Ca^{2+} + 2OH^-$$ Portlandite Dissolution

$$Ca^{2+} + HCO_3^- + OH^- \longrightarrow CaCO_{3(s)} + H_2O$$ CSH Degradation

$$H^+ + CSH \rightarrow Ca^{2+} + H_2O + SiO_2 \cdot H_2O_{(amorphous)}$$

- **Reservoir chemistry –**

Field monitoring data, medium value



- **Minerology –**

Caprock: field monitoring data
Cement: Class H cement composition

Mineral	Volume fraction	Mineral	Volume fraction
Shale		Cement	
Calcite	53.38	CSH	58.21
Dolomite	2.15	Portlandite	28.89
Illite	10.28	Monosulfate	9.96
Kaolinite	1.70	Kaotite	2.90
Quartz	29.3		

Mass Transfer

- **Relative permeability & Capillary pressure**

Relative permeability				
Rock domain	λ	S_{lr}	S_{ls}	S_{gr}
Cement	0.457	0.3	1.0	0.05
Fracture	0.457	0.3	1.0	0.05

Capillary pressure					
Rock domain	λ	S_{lr}	S_{ls}	$1/P_0$	P_{max}
Cement	0.457	0.0	0.999	1.6×10^{-7}	10^8
Fracture	0.457	0.0	0.999	5.1×10^{-5}	10^7

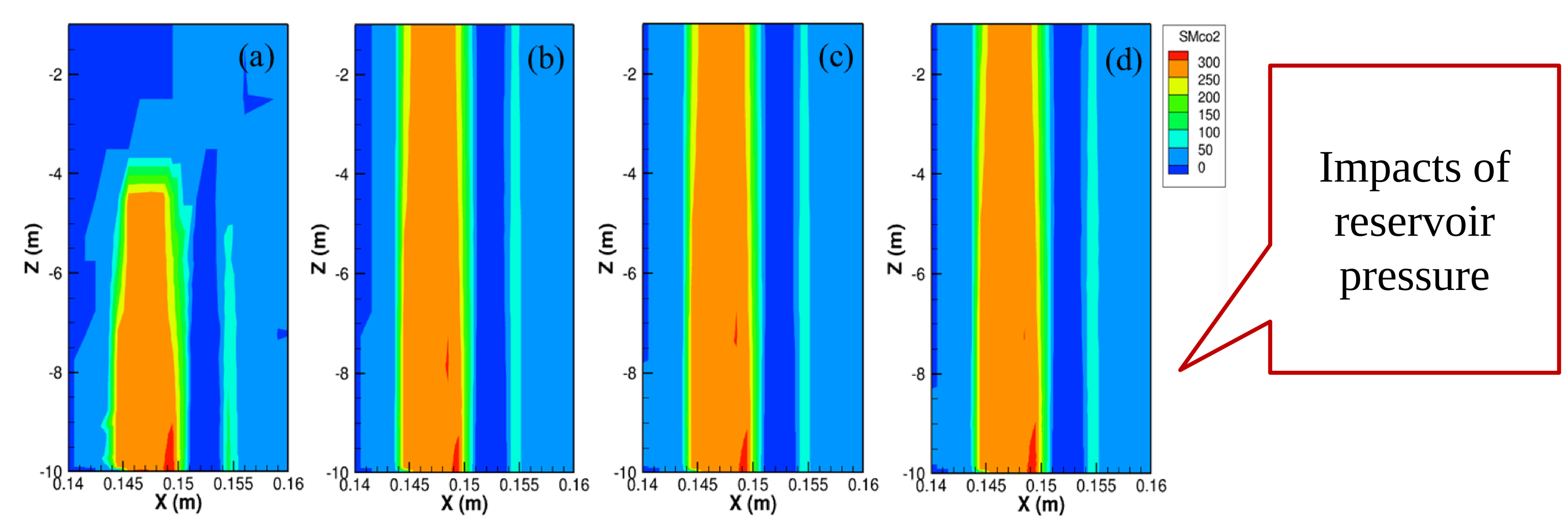
- **Diffusion**

$$D^{eff} \propto \tau \cdot \phi \cdot D$$

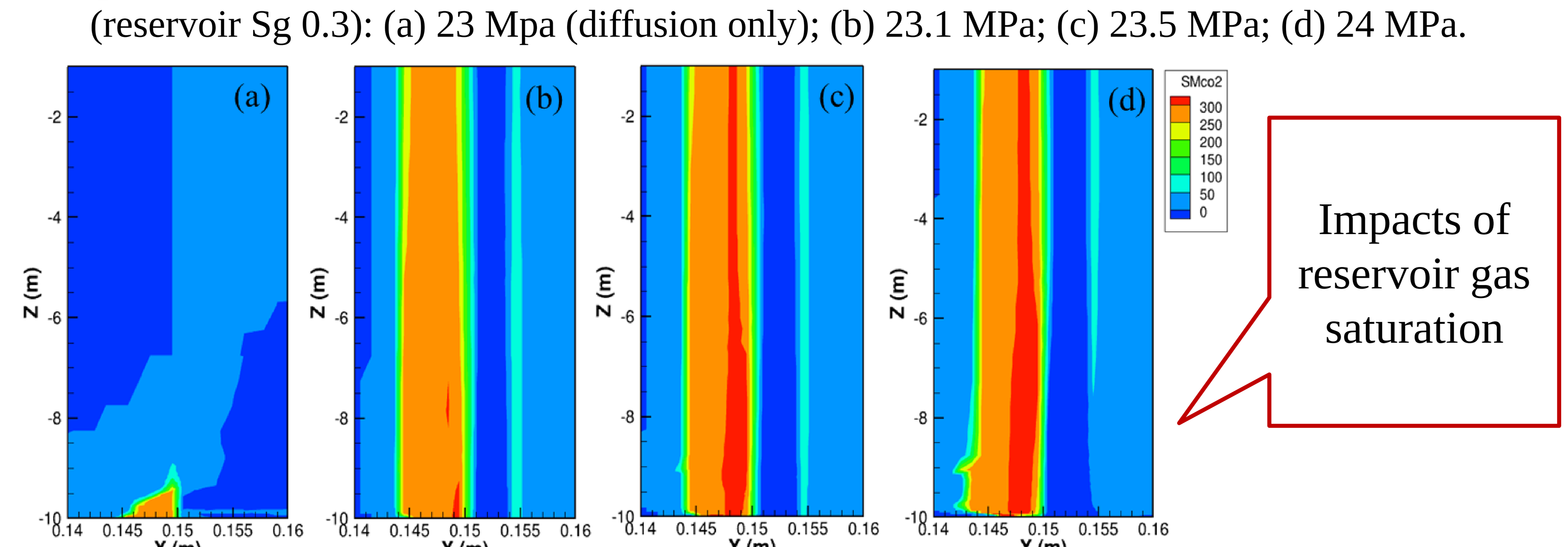
$$where: \tau - Tortuosity$$
$$\phi - Porosity$$
$$D - Diffusion\ Coefficient$$

For cement, set:
$\tau = 0.01$, $D = 10^{-11}$ m^2/s

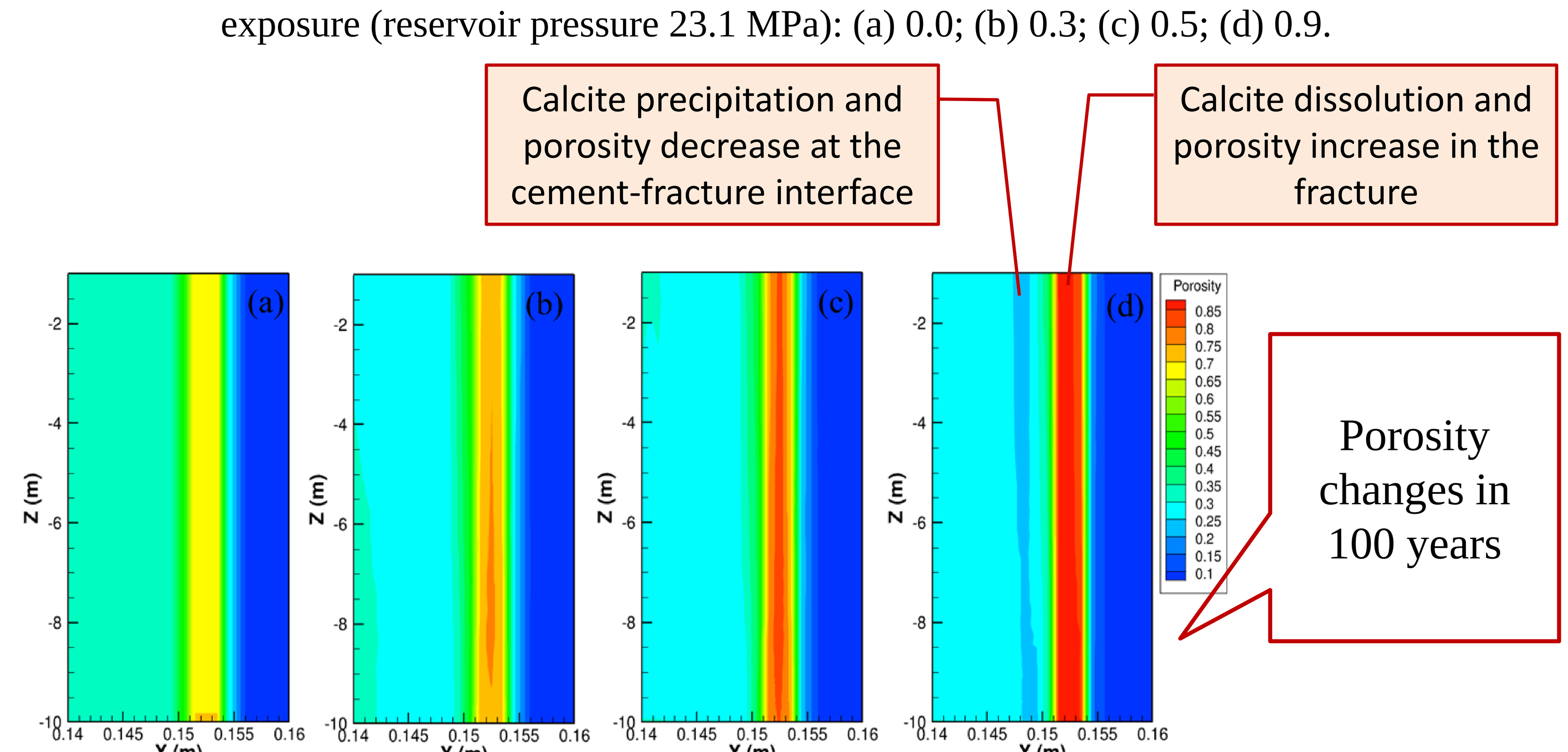
Results



CO_2 sequestered in mineral phase (kg/m^3) with different reservoir pressure after 30 yr exposure (reservoir Sg 0.3): (a) 23 Mpa (diffusion only); (b) 23.1 MPa; (c) 23.5 MPa; (d) 24 MPa.



CO_2 sequestered in mineral phase (kg/m^3) with different gas saturation (Sg) after 30 yr exposure (reservoir pressure 23.1 MPa): (a) 0.0; (b) 0.3; (c) 0.5; (d) 0.9.



Porosity changes in 100 year simulation time (reservoir Sg 0.3, reservoir pressure 23.1 MPa): (a) 0 year; (b) 10 year; (c) 30 year; (d) 100 year.

Conclusions

- ✓ Operational reservoir pressure and reservoir gas saturation (Sg) affect the height of the carbonated zone along an existing fracture.
- ✓ For typical wellbore cements that undergo exposure to long-term CO_2 injection, integrity will likely be maintained for at least 100 years.
- ✓ If an acid plume enters an existing limestone caprock fracture, calcite would likely dissolve, increasing fracture permeability.

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Presenter's information:
Department of Civil & Environmental Engineering; Energy & Geoscience Institute
The University of Utah, Salt Lake City, Utah, 84112, USA
Email: b.j.mcpherson@utah.edu