Evolution of Cement Compositional and Transport Properties During Geological Carbon Sequestration

NETL-RUA Regional University Alliance

Technology Overview

- Assessing the possibility of CO_2 leakage is one of the major challenges for geological carbon sequestration
- During geological carbon sequestration injected CO_2 can react with wellbore cement, and potentially changes its composition and transport properties

In this work, we develop a reactive transport model to understand and predict the cement alterations when in direct contact with CO_2, and how such interaction change transport properties.

- Interaction between CO_2 saturated brine and cement leads to localized change in porosity with the creation of higher and lower porosity zone
- Local reduction in porosity leads to a decrease in penetration rates of the reaction front
- Initial portlandite content versus porosity plays a key role in determining the ultimate characteristics of the calcite zone and the extent of porosity reduction
- Higher initial portlandite per pore volume ratio leads to lower alteration depth
- Relative increase in porosity controls the increase in effective permeability of cement

Methodology

CrunchFlow, a reactive transport code, was used to simulate multicomponent reactive flow and transport processes.

Main Reactions

$Ca(OH)_2(s)+2H^+ \Leftrightarrow Ca^{2+}+2H_2O$ Portlandite dissolution

$C-S-H(s)+H^+ \Leftrightarrow Ca^{2+}+H_2O+SiO_2(aq)$ C-S-H dissolution

$CaCO_3(s) \Leftrightarrow Ca^{2+}+CO_3^{2-}$ Calcite precipitation / dissolution

Permeability

- Permeability was estimated using the following permeability-porosity relation

$$\frac{perm}{perm_0} = \left(\frac{\phi}{\phi_0}\right)^n$$

Ghabezloo, S., J. Sulem, et al. (2009).

Where :
- *perm* is the permeability
- $perm_0$ is the initial permeability
- Φ is the porosity
- Φ_0 is the initial porosity
- n is a correlation exponent

Effective Permeability

Based on parallels beds formulation

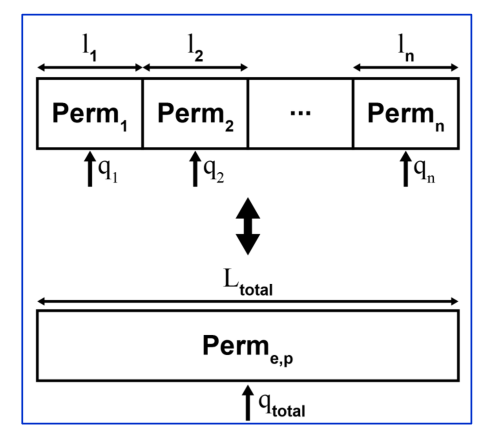

Figure 1 – Illustration for the calculation of parallel effective permeability.

$$perm_{e,p} = \frac{\sum_{i=1}^{n_{tot}} perm_i \cdot l_i}{\sum_{i=1}^{n_{tot}} l_i}$$

Where
- l_i length of the i^th layer
- q_i flow in the i^th layer
- L_{total} total length of the core
- $perm_e$ effective permeability of the core
- q_{total} total flow in the core

$$\beta_p = \frac{perm_{e,p}}{perm_{e,0}}$$

Calculation of the relative order of magnitude change in effective permeability

Results

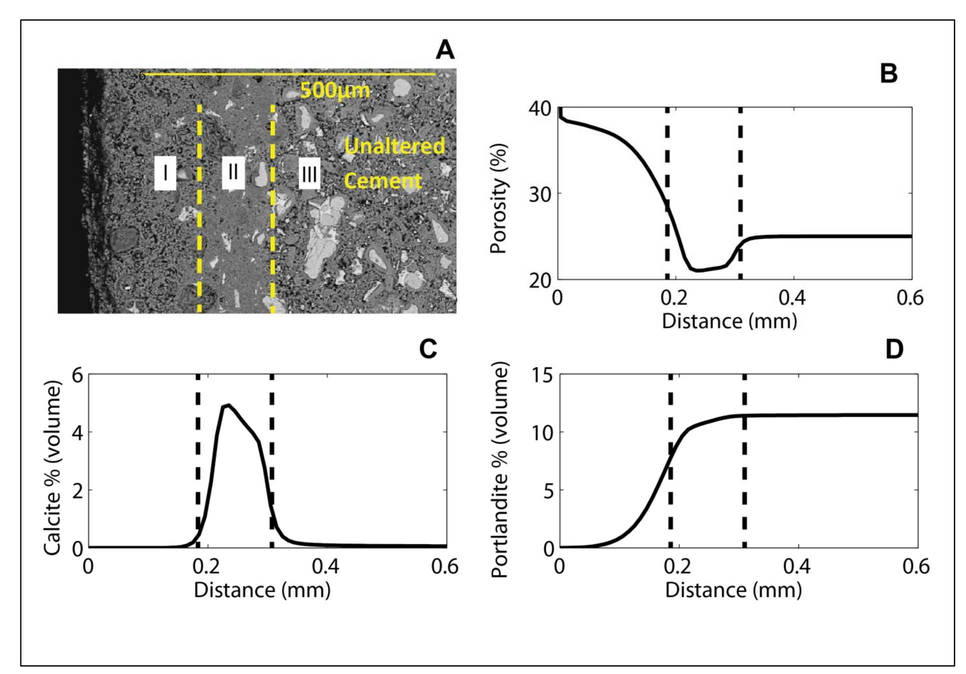

Figure 2 – Laboratory observation and simulation output at day 9 of exposure in the cement core at 50°C and 30.3 MPa, with cement-brine interface at the 0 mm. (A) SEM-BSE image of cement (Kutchko, Strazisar et al. 2008); (B)-(D) Predicted spatial profiles of properties for (B) porosity, (C) calcite volume fraction, (D) portlandite volume fraction.

After exposure a zonation can be observed with a first zone close to the interface which had been significantly altered. In the second zone calcite precipitation occurs second with a decrease in porosity. The third zone present almost no change in structure and composition.

- Calcite precipitation induce a reduction in porosity reducing the overall diffusion of acidic brine toward the inner core.
- Portlandite is strongly depleted in the first zone which will be significantly altered.

we define φ as the portlandite content over porosity ratio:

$$\varphi = \frac{Initial\ portlandite\ content\ (\%volume)}{Initial\ porosity\ (\%volume)}$$

It essentially corresponds to the initial volume "density" of the portlandite in the cement pore space.

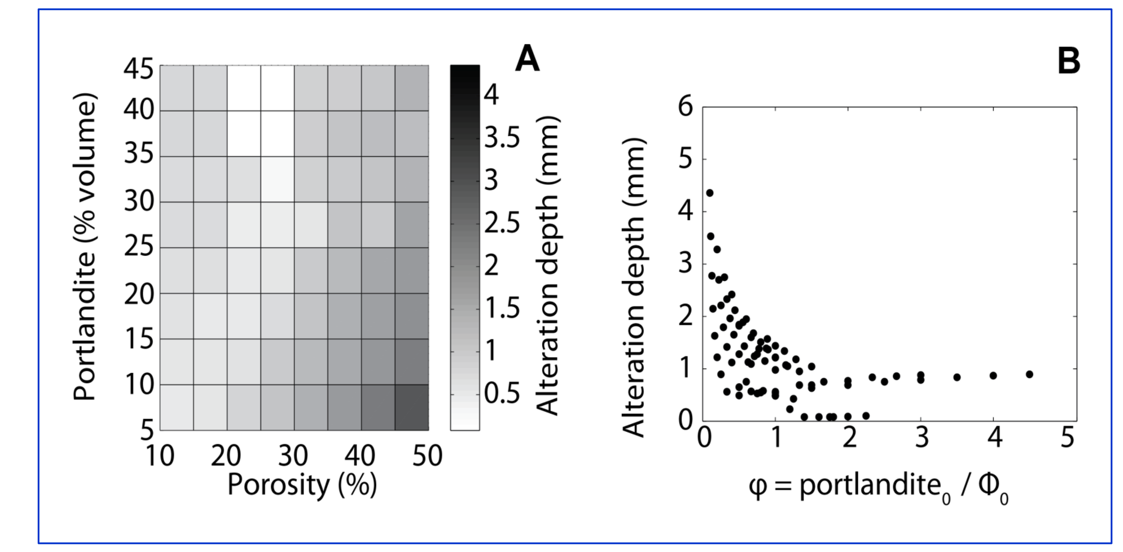

Figure 3 – Simulation results of alteration depth after 200 days of exposure to CO_2-saturated brine. (A) Alteration depth as a function of initial portlandite content and porosity. (B) Alteration depth as a function of initial portlandite content and porosity ratio.

- Alteration depth increases with an increase in initial porosity
- Alteration depth decrease with increasing initial portlandite content
- In general higher initial portlandite per pore volume ratio leads to lower alteration depth

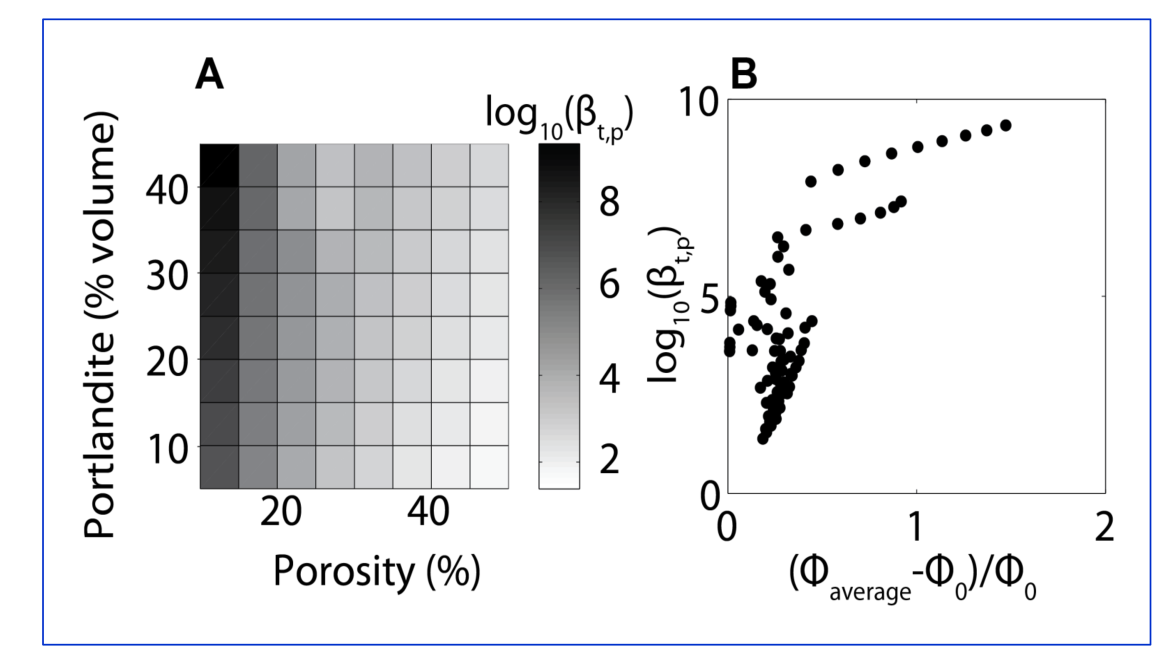

Figure 3 – Relative change in effective permeability for parallels beds as a function of A) initial portlandite content and porosity. B) the relative porosity at 200 days .

- Effective permeability is increasing with time
- Increase in effective permeability with increasing relative average porosity
- Higher relative changes are observed for lower initial porosity

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