EGU26
GENERAL ASSEMBLY

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Low field NMR Reveals various Pore-Scale Carbonate Dissolution patterns

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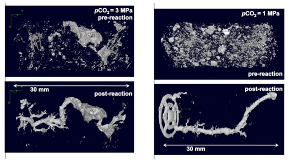
Backgound and Motivation

Why dissolution pattern matters ???

- Reactive transport dictates structural evolution across CO2 Geological Sequestration, Karst Formation, and Acid Stimulation.
- Dissolution patterns fundamentally govern fluid-solid interactions in porous media, which serves as a critical factor in both geological and industrial processes.

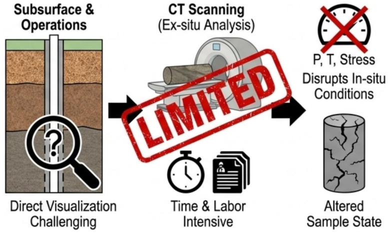
Face dissolution (Mahmoud et al., 2016)



Wormhole and channeling (Smith et al., 2013)

How to distinguish these regimes ???

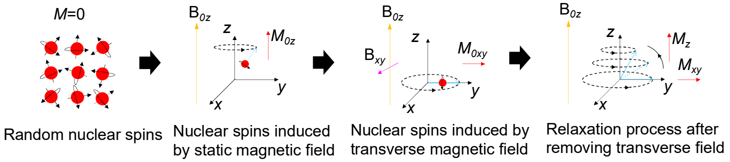
Despite its importance, the **direct visualization** of dissolution transitions remains challenging in practical engineering. Conventional CT methods disrupt in-situ conditions and require significant labor.



What we do ???

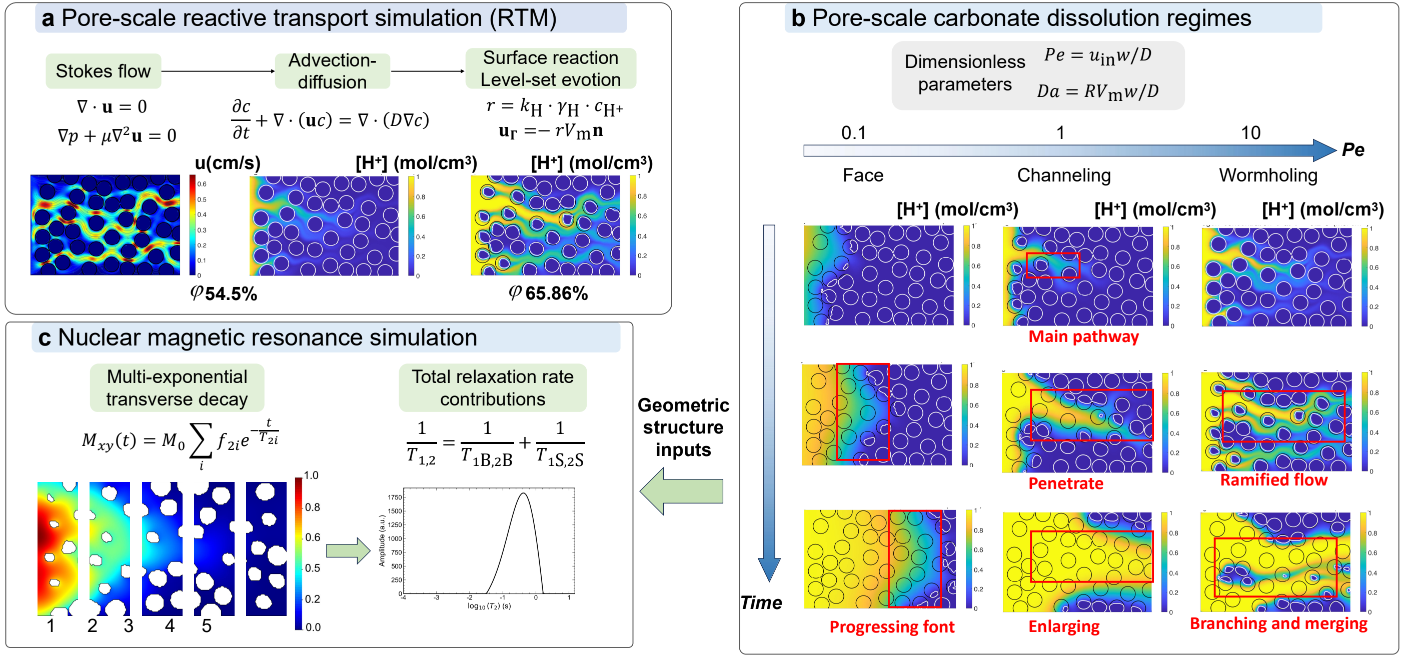
Nuclear Magnetic Resonance (NMR) is a cost-effective, non-invasive technology with a unique sensitivity to water, which is able to characterize the pore size and fluid exchange in porus media.

NMR measurements are based on the behavior of the magnetic spin of protons inside changing magnetic fields, and involve aligning proton spins with a static magnetic field (B_0) to produce magnetization (M_{0z}), perturbing the alignment with a secondary magnetic field (B_1) to produce magnetization (M_{0xy}), and excited spins returning to equilibrium through relaxation after the removal of the second field .



- **We develop a coupled reactive transport and NMR simulation framework for pore coupling dynamics in carbonate dissolution**
- **Dissolution regimes can be quantitatively distinguished through the evolution of T_2 distribution**

Numerical Simution Framwork

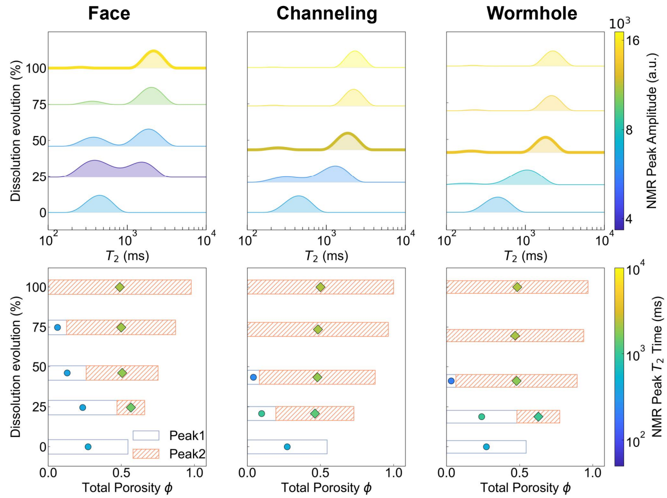


$$\nabla \cdot \mathbf{u} = 0$$
$$\nabla p + \mu \nabla^2 \mathbf{u} = 0$$
$$\frac{\partial c}{\partial t} + \nabla \cdot (\mathbf{u}c) = \nabla \cdot (D \nabla c)$$
$$r = k_{\mathrm{H}} \cdot \gamma_{\mathrm{H}} \cdot c_{\mathrm{H^+}}$$
$$\mathbf{u}_{\Gamma} =- rV_{\mathrm{m}}\mathbf{n}$$
$$Pe = u_{\mathrm{in}} w/D$$
$$Da = RV_{\mathrm{m}} w/D$$
$$M_{xy}(t) = M_0 \sum_i f_{2i} e^{-\frac{t}{T_{2i}}}$$
$$\frac{1}{T_{1,2}} = \frac{1}{T_{1\mathrm{B},2\mathrm{B}}} + \frac{1}{T_{1\mathrm{S},2\mathrm{S}}}$$

Figure 1 Modeling framework integrates reactive transport and NMR simulations to elucidate the mechanisms and spatiotemporal dynamics of carbonate dissolution.

- **Face dissolution:** Reactants are rapidly consumed near the inlet because diffusion dominates over advection.
- **Wormholing:** As advection strengthens, reactants preferentially invade and continuously widen initial high-permeability pathways.
- **Channeling**: Strong advection promotes localized dissolution enlarging pathways, drawing in even more reactant into branching pathways.

T_2 distribution across Dissolution Regimes



- **Face Dissolution (*Pe*=0.1):** Exhibits a persistent bimodal distribution due to weak pore coupling. The matrix-pore T_2 (100–1000 ms) remains constant while its amplitude decreases, indicating matrix consumption without pore size alteration.
- **Wormholing (*Pe*=10):** Maintains a broad single-peak morphology driven by strong pore coupling and active fluid exchange. Both matrix and vug peak centers shift to longer T_2.
- **Channeling (*Pe*=1):** Features a short-lived bimodal distribution that rapidly merges into a single, long-relaxation peak. The rapid reduction of the amplitude of the shorter-relaxation components is attributed to the penetration of the main flow pathway.

Figure 2 Dynamic evolution of T_2 distribution and pore-class porosity partitioning across face, channeling, and wormholing dissolution regimes in a random pore network.