InterPore2026 IMPERIAL

Pore-scale Dynamics of Multiphase Reactive Transport in Carbonates under CO_2-acidified Brine Injection

Qianqian Ma, Rukuan Chai, Zhuangzhuang Ma, Yanghua Wang, Martin J. Blunt, Branko Bijeljic

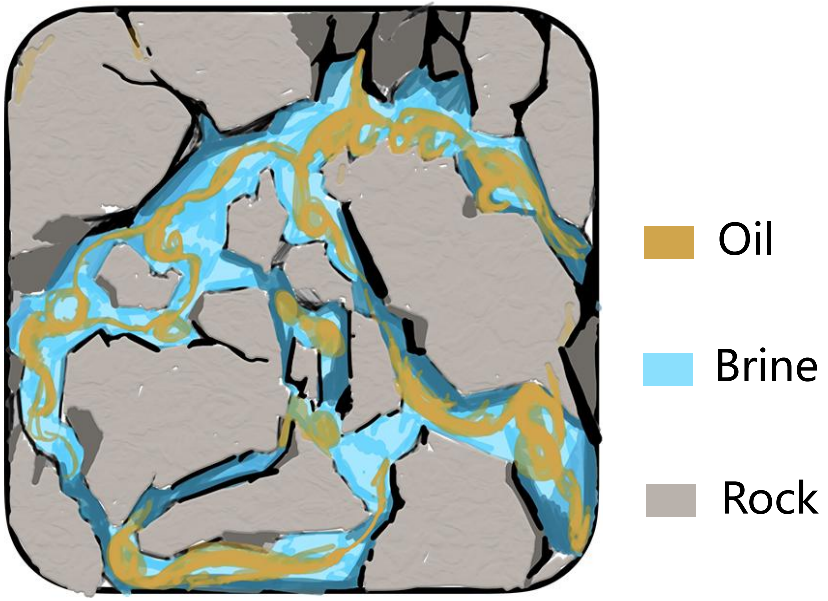
Centre for Reservoir Geophysics · Resource Geophysics Academy · Imperial College London

19 MAY 2026

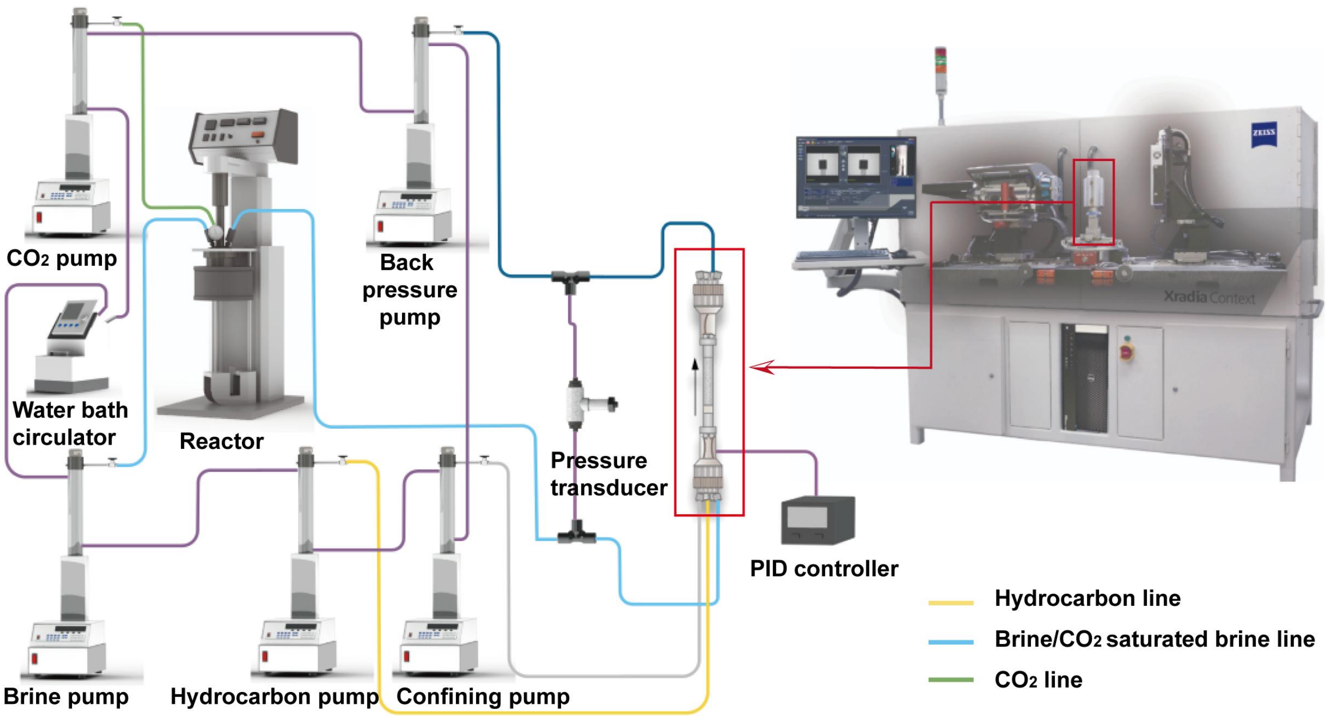
Challenges

Reactive transport & multiphase flow

- **Transport heterogeneity**: Hydrocarbon redistributes flow paths across the pore network.
- **Reaction**: Hydrocarbon phase may block the CO_2 equilibrated brine from reacting.
- **Mass transfer**: CO_2 partitions into oil ganglia, driving swelling and capillary pressure redistribution.



Experimental apparatus



Measurement System

1. Fluid Flow Unit

ISCO Pumps
High T&P Reactor
High T&P Core Holder
Back Pressure Regulator

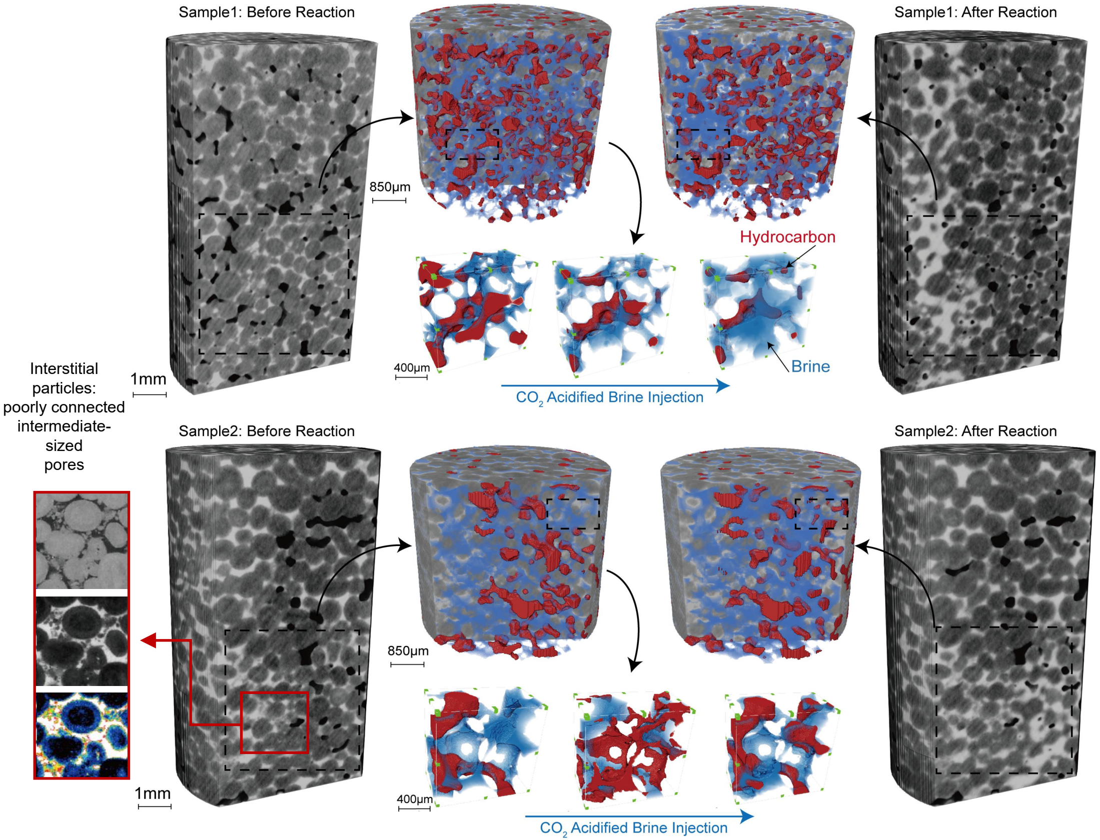
2. Monitoring Unit

X-ray CT
Pressure Transducer

3. Stability Unit

Water Bath Circulator
PID Controller
Insulation Cover for Tubing

Objective 1: How does pore-scale heterogeneity shape dissolution patterns and effective reaction rates?



- **Dual heterogeneity**
  - Pore-scale structural heterogeneity.
  - Residual oil distribution.
- **Oil mobilisation**
  - Dissolution enables oil mobilisation; mobilisation reshapes the dissolution pattern.
- **Dynamic evolution**
  - Structure, fluids, and reaction co-evolve — the dissolution pattern cannot be read from initial conditions.

Key findings

- Two-phase flow reaction rates are transport-limited and lower than single-phase or batch rates.
- We captured micron-resolution displacement dynamics, leading to channel formation that increased porosity and permeability.
- Heterogeneity of pore structure, hydrocarbon distribution, and re-mobilization controlled the dissolution patterns and effective reaction rates.

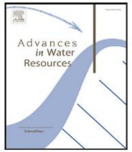
Advances in Water Resources 208 (2026) 105202

ELSEVIER

Contents lists available at ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres



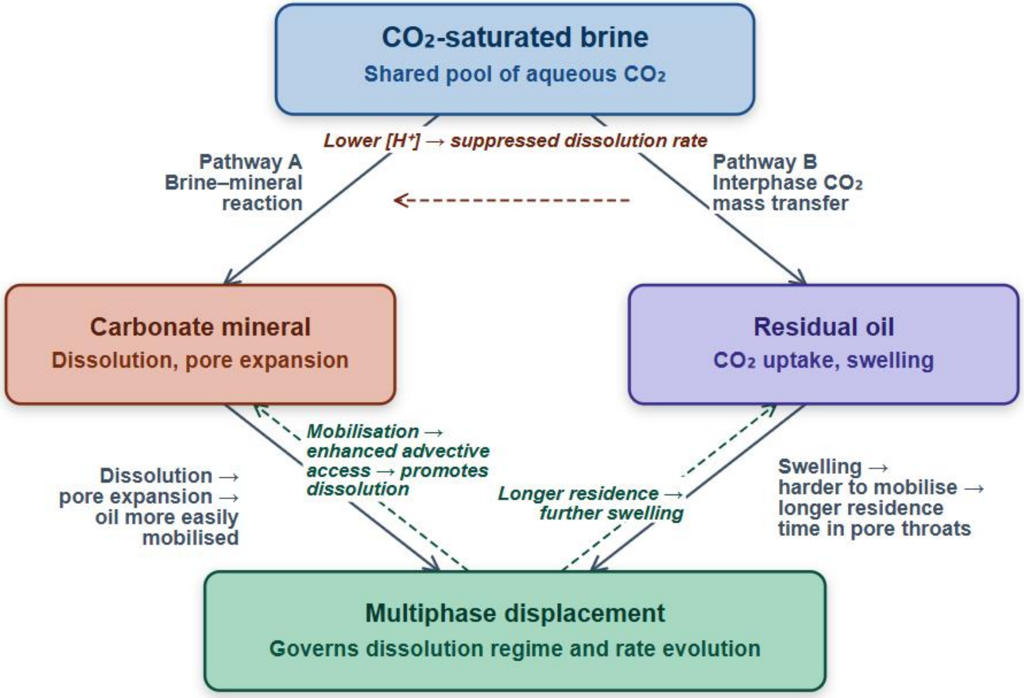
Check for updates

Pore-scale dynamics of multiphase reactive transport in water-wet carbonates under co_2-acidified brine injection: Dissolution patterns and reaction rates

Qianqian Ma[a,b], Rukuan Chai[b], Sajjad Foroughi[b], Yanghua Wang[a,b], Martin J. Blunt[a], Branko Bijeljic[a,*]

Scan for Paper

Objective 2: How does hydrocarbon swelling and mobilisation compete to govern the effective reaction rate?



Three coexisting phases

- CO_2 - saturated brine, carbonate mineral, residual hydrocarbon

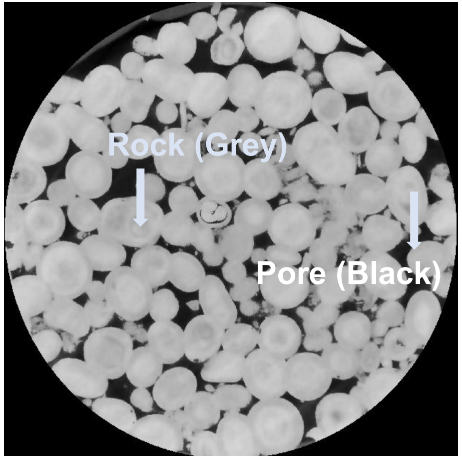
Two reactive pathways

- Brine - mineral reaction → dissolution
- Interphase CO_2 transfer → hydrocarbon swelling

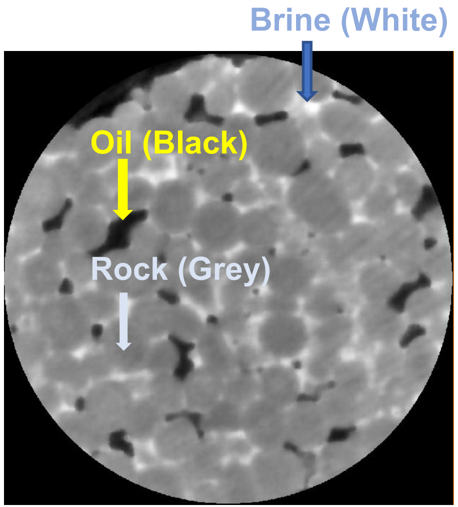
Coupled through multiphase displacement

- Dissolution enables oil mobilisation
- Swelling prolongs ganglion residence

Carbonate sample & injection protocol



Sample



S_{or}= 30.2%

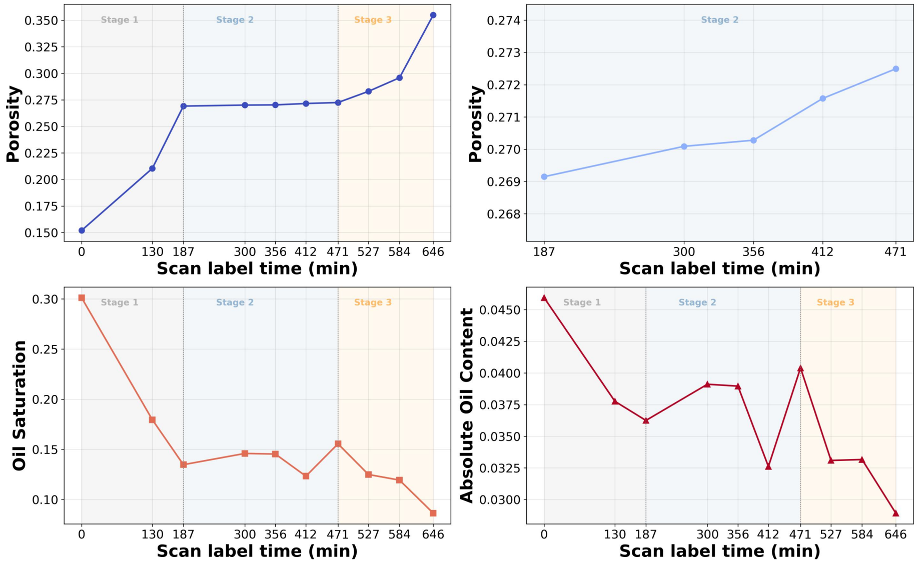
Scan	Time interval (Start–End) (min)	Pore volumes
0 min scan	Residual oil saturation scan	
130 min scan	t=83 to t=130	330
187 min scan	t=140 to t=187	465
300 min scan	t=254 to t=300	677
356 min scan	t=210 to t=356	782
412 min scan	t=366 to t=412	886
471 min scan	t=425 to t=471	990
527 min scan	t=481 to t=527	1094
584 min scan	t=537 to t=584	1195
646 min scan	t=597 to t=646	1294

Injection Protocol

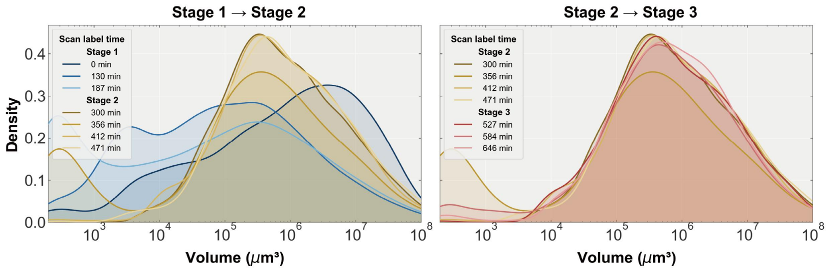
- 0 ~ 73 min: Constant flow at 0.1 mL/min
- 73 ~ 646 min: Cyclic flow — 0.5 mL/min (10 min) → 0.1 mL/min (~ 47 min), ×10
- Total duration: 646 min

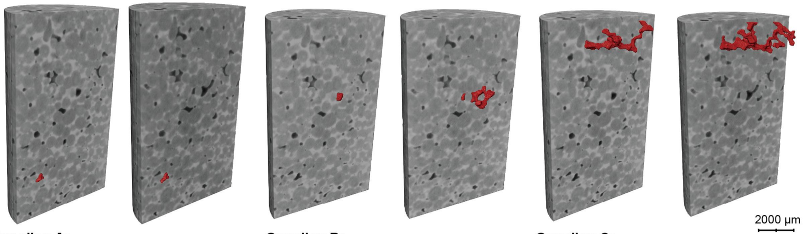
Carbonate dissolution proceeds in three distinct stages

porosity, oil saturation, and oil content



ganglia distribution and size





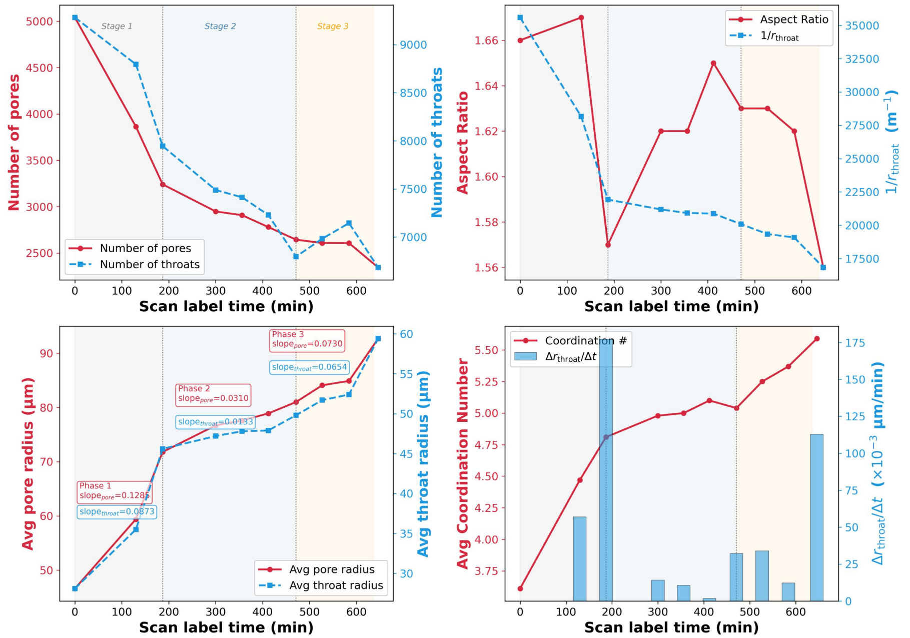
Ganglion A:
187 min (Left): Volume=1.96×10⁷ μm²
300 min (Right): Volume=2.14×10⁷ μm²

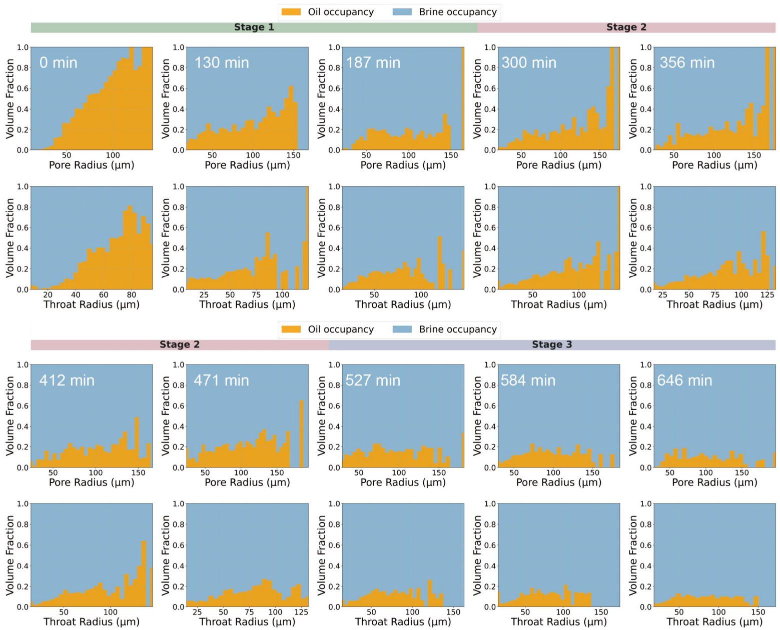
Ganglion B:
187 min (Left): Volume=7.60×10⁷ μm²
300 min (Right): Volume=1.67×10⁸ μm²

Ganglion C:
187 min (Left): Volume=2.37×10⁸ μm²
300 min (Right): Volume=3.89×10⁸ μm²

- Stage 1 (0 ~ 187 min): Porosity rises linearly; oil saturation and ganglia size both decrease sharply.
- Stage 2 (187 ~ 471 min): Porosity plateaus; absolute oil volume rebounds — swollen ganglia grow and coalesce in place.
- Stage 3 (471 ~ 646 min): Porosity resumes rising; oil volume declines — under identical injection conditions.

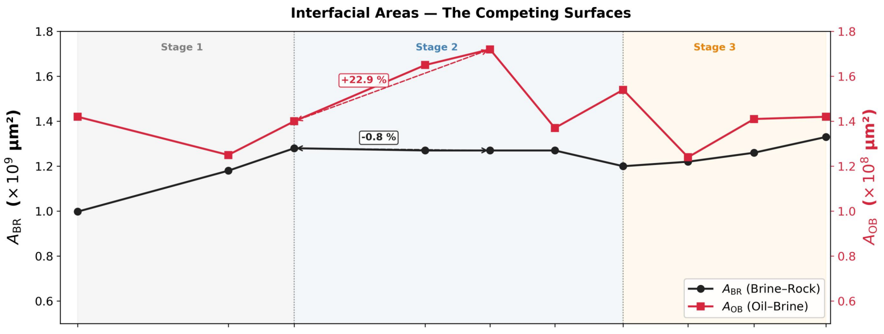
Pore-space geometry, topology, and fluid occupancy

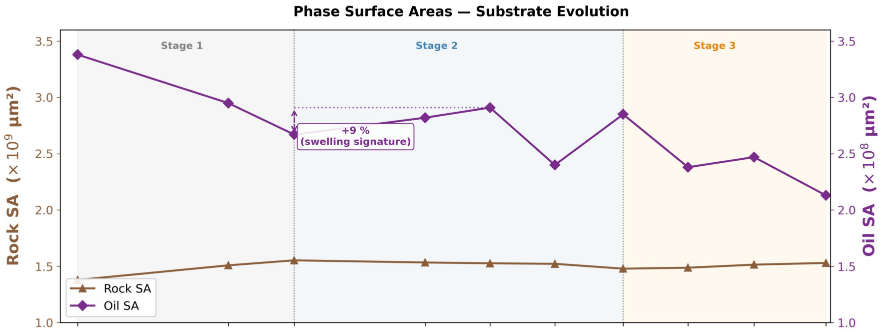


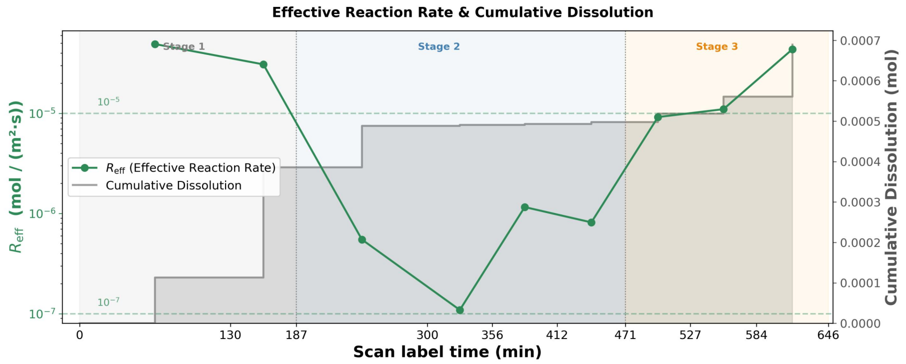


- Stage 1: Dissolution widens throats and enhances connectivity; oil is progressively displaced from the network.
- Stage 2: Swollen ganglia reoccupy the largest throats and block preferential flow paths; occupancy peaks at 73% for throats >140 μm.
- Stage 3: Dissolution reopens flow paths and restores connectivity; oil is rapidly displaced from the largest throats.

Interfacial area and dissolution rate

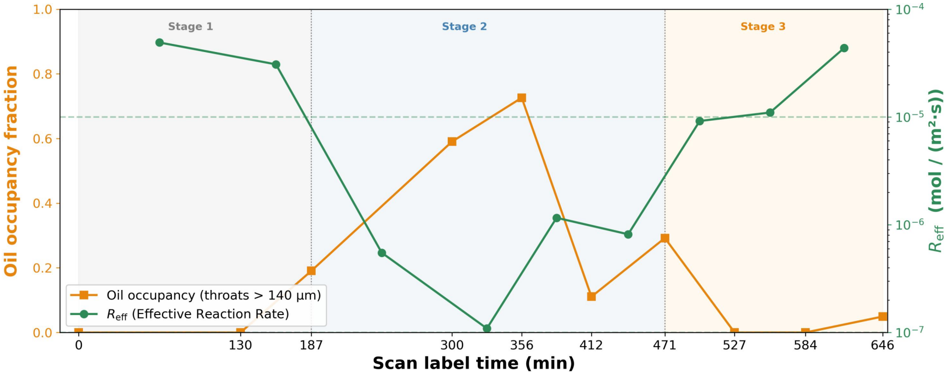


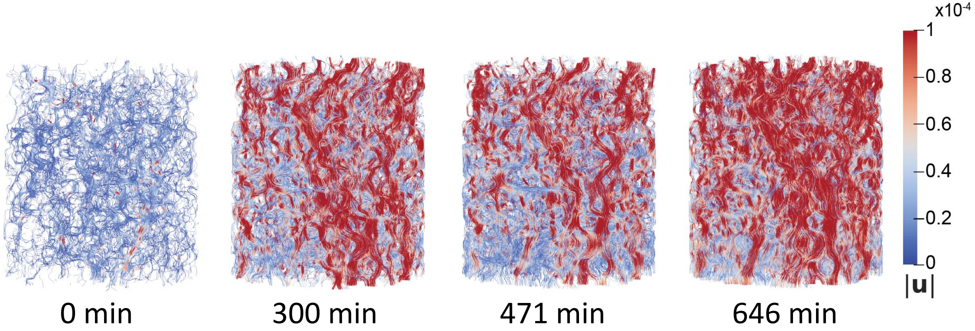




- During Stage 2, oil–brine interface grows 23%.
- Brine–rock interface stays flat.
- The effective reaction rate is non-monotonic over time and decreases a hundredfold. Much lower than batch (uniform) reaction rate.

Why does carbonate dissolution nearly stop and then recover?





Geometric factors dominate over chemical

- Chemical — ganglia absorb CO_2 and reduce H^+ availability in the bulk brine.
- Geometric — swollen ganglia blocks acidic brine access to solid surface.

Mobilisation drives reaction rate recovery

- Once dissolution opens bypass routes, ganglia are remobilised, advective contact is restored, and the reaction rate recovers.

Competition:

- Swelling vs mobilisation governs advective access.

Conclusions

- Time-resolved micro-CT captures three stages of carbonate dissolution during CO_2-saturated brine injection in hydrocarbon-bearing rock.
- Dissolution is initially rapid and then drops a hundredfold as hydrocarbon swells and blocks access of acidic brine to the mineral surface.
- The effective dissolution rate reflects a competition between hydrocarbon swelling and ganglion mobilisation, which together govern advective access to mineral surfaces and cause non-monotonic reaction behaviour over time.
- Multiphase reactive transport introduces additional dynamic complexity, which should be considered in the design of CO_2 storage

Thank You

Questions & Discussion

Qianqian Ma

PhD Candidate

Resource Geophysics Academy

Imperial College London

✉ q.ma23@imperial.ac.uk

Scan for LinkedIn

Scan for Wechat

Acknowledgments

Supervisors: Dr. Branko Bijeljic, Prof. Martin Blunt

Publications

Paper 1: Ma et al., Advances in Water Resources, 208 (2026), 105202

Paper 2: arXiv preprint