Exploiting induced carbonate precipitation to improve reservoir storage integrity and geothermal system efficiency

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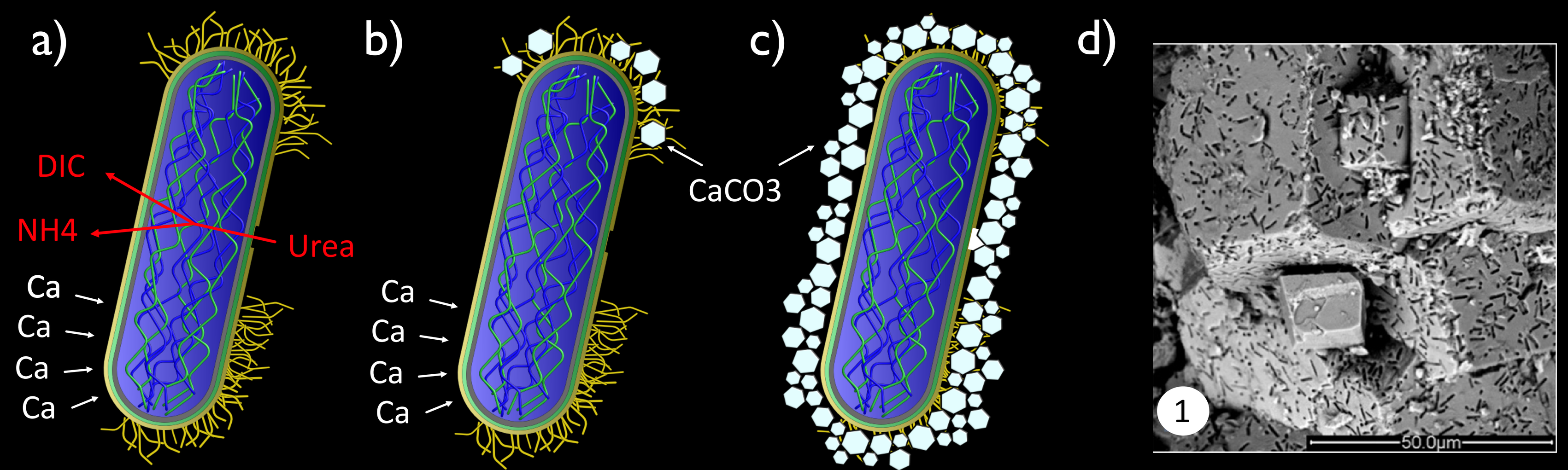
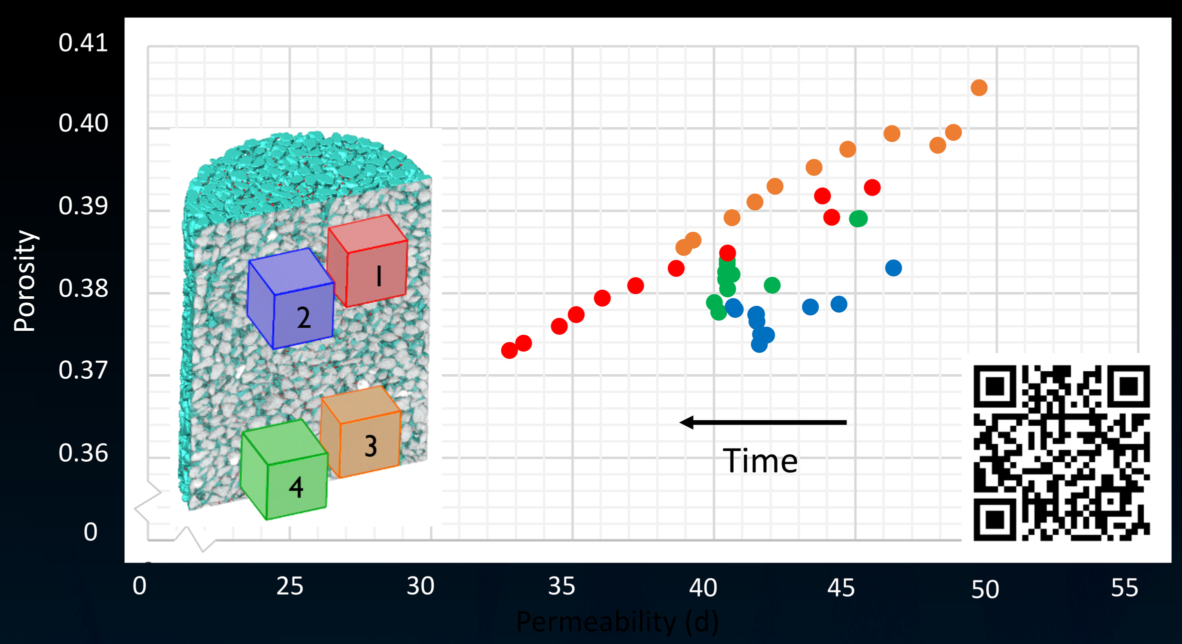
The dynamics of biologically induced crystallization

What is ureolytic induced carbonate precipitation (UICP)?

UICP mimics a naturally occurring biomineralization process caused by soil bacteria that produce the enzyme urease. We investigate the subsurface engineering applications of this intra-aggregate precipitation process using real-time 4D (3D + time) X-Ray Computed Tomography (XCT).



The mechanism of calcite nucleation on the cell walls of urease producing bacteria (a-c). d) shows a scanning electron microscope image of microbially induced CaCO3 [1]. The indentations are what is left of bacterial cells that became entombed in the growing calcite crystal.

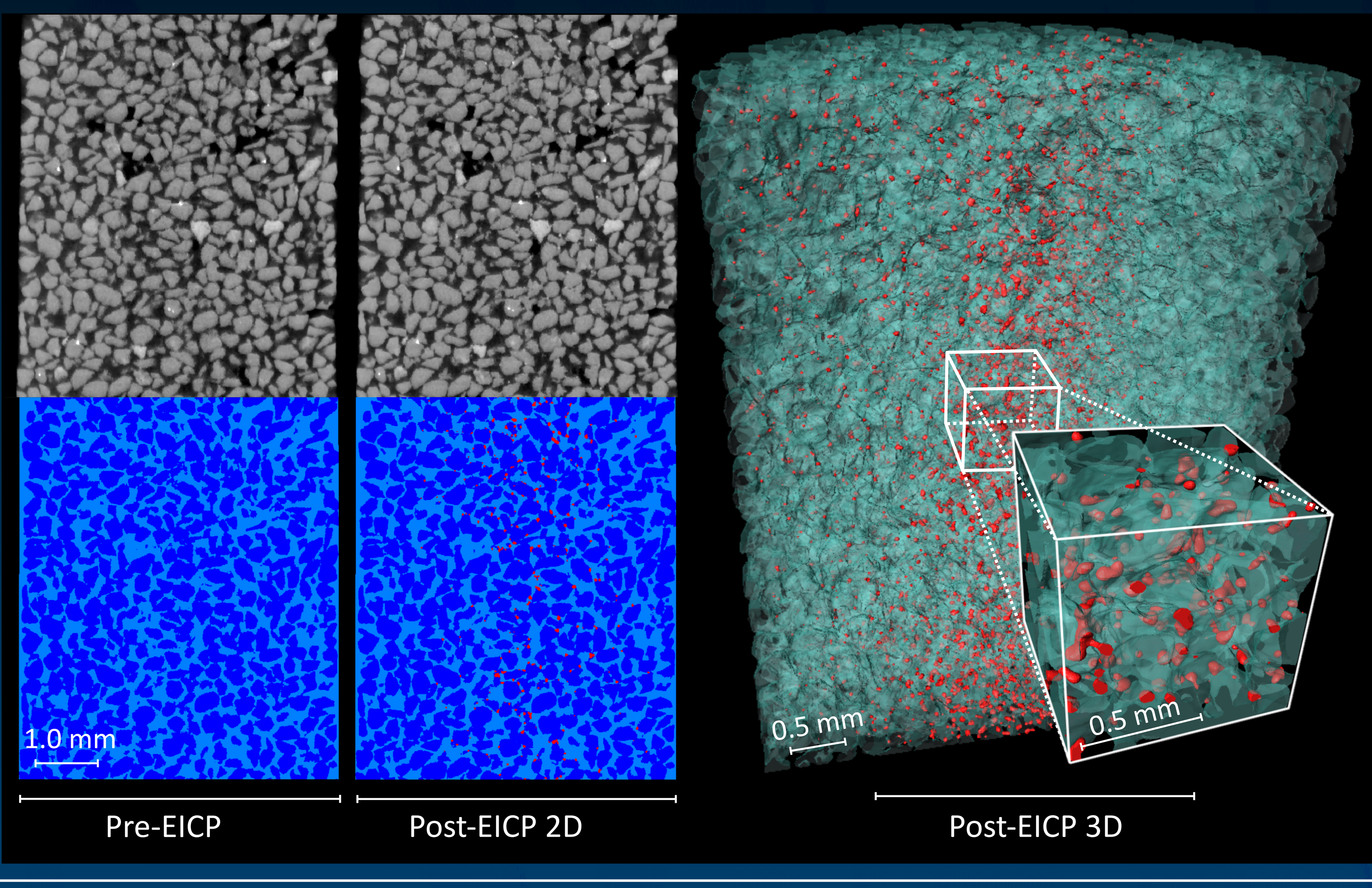


Synergy between intrinsic and environmental variables

Saturation states, Nucleation and Growth

Complexity From Microscopic to Macroscopic scales

Porosity/permeability relationships during a 1 hour UICP treatment cycle of subvolumes selected relative to local crystal density. Subvolumes 1 and 3 are within the main precipitation band. Subvolumes 2 and 4 are within a less precipitated region. The QR code shows a video of the distribution of calcite in 3D

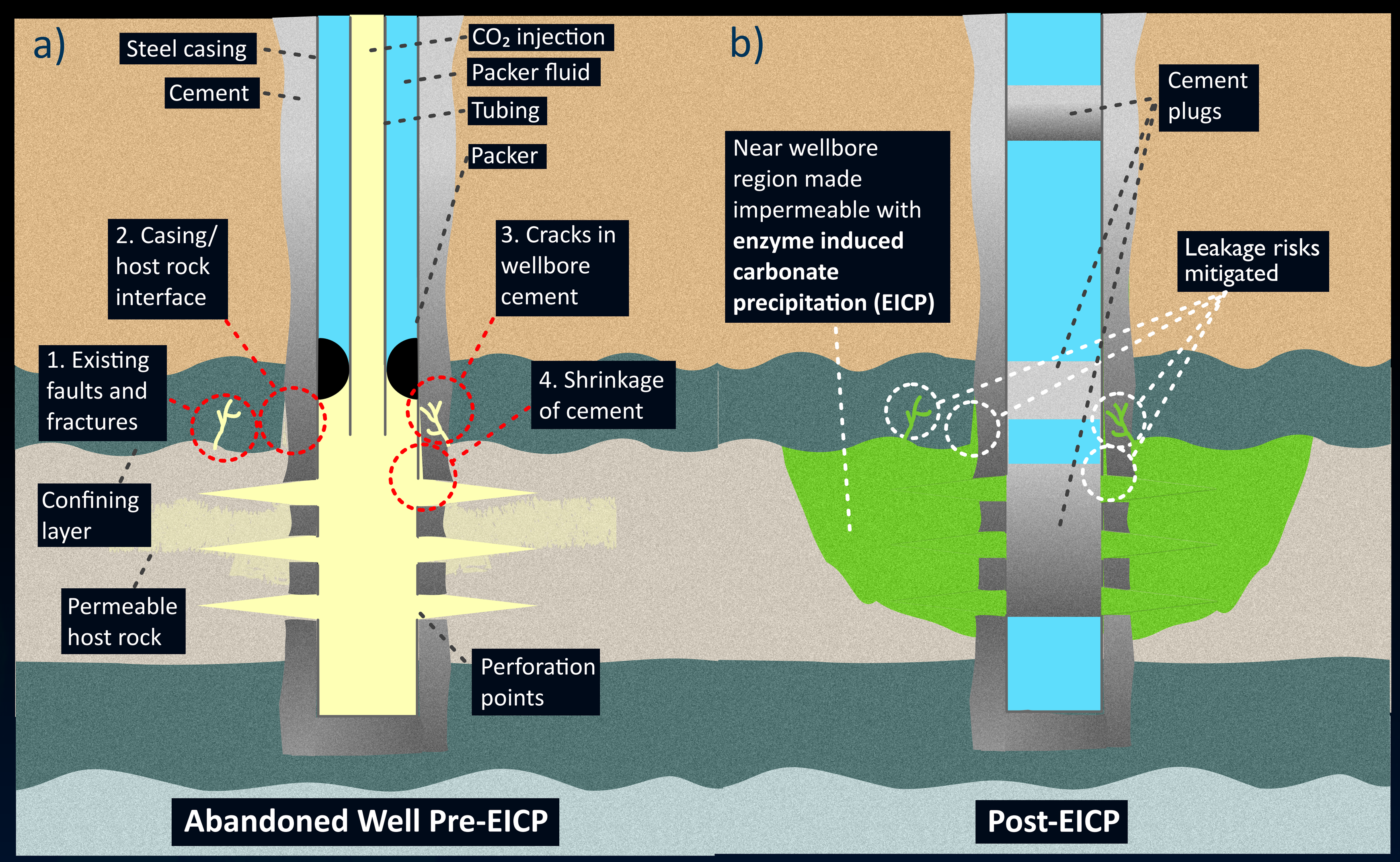


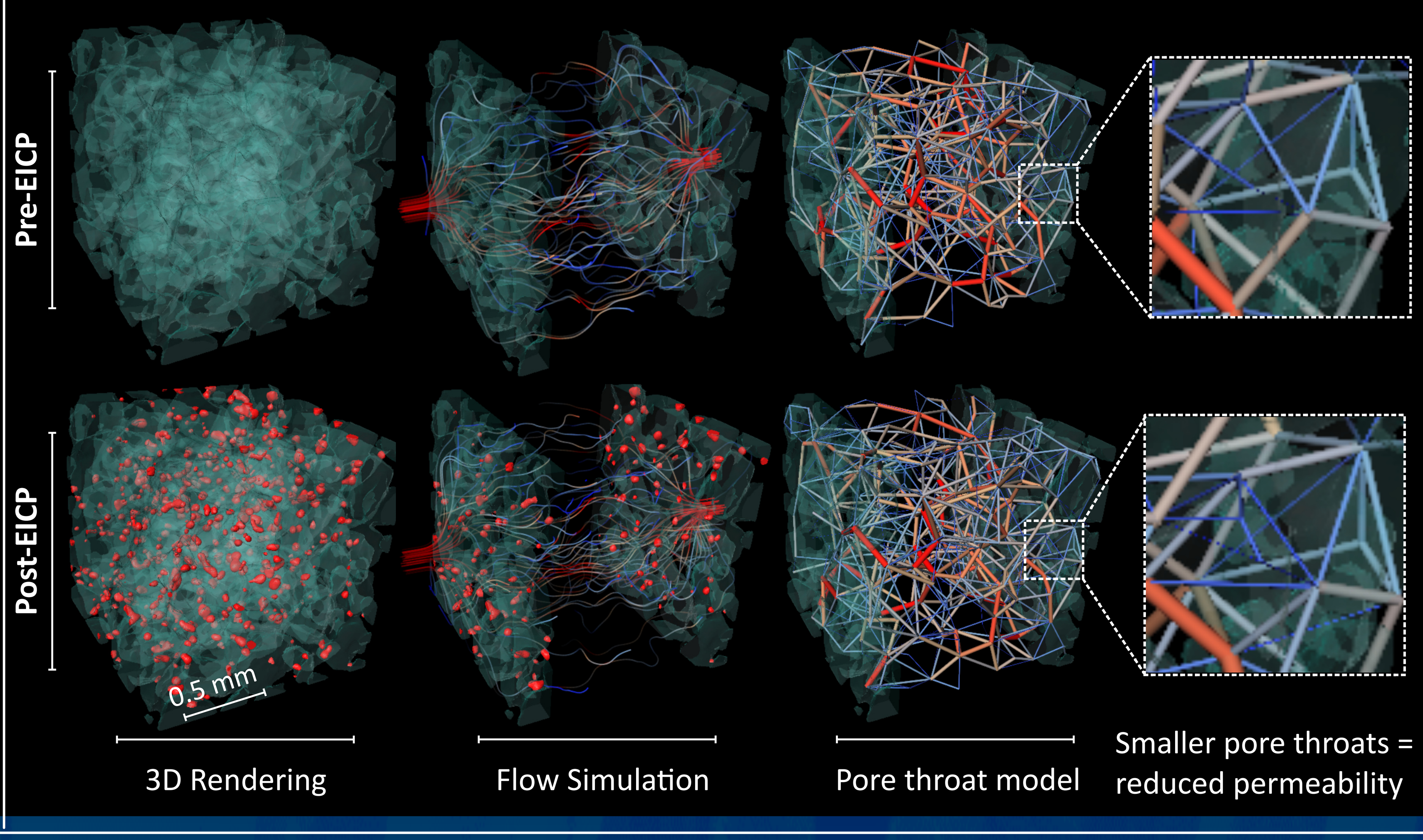
CO_2 Storage & Utilisation: Improving storage integrity

Reduced permeability, Reduced leakage risk

When CO_2 dissolves in water it forms carbonic acid, which is corrosive to carbonate minerals. We plan to explore the buffering effect of dissolved calcite on migration of the reactive front. By better understanding how pore networks develop during UICP, and in the presence of CO_2 enriched brines, the required volume of biomineralized material is calculated, and experimentally validated to prevent leakage.

- In situ environmental conditions using high temperature and pressure flow cells
- Digital volume correlation (DVC) is used to characterize the dissolution front
- Permeability simulation and pore network modeling allow correlation between microstructural properties and fluid flow

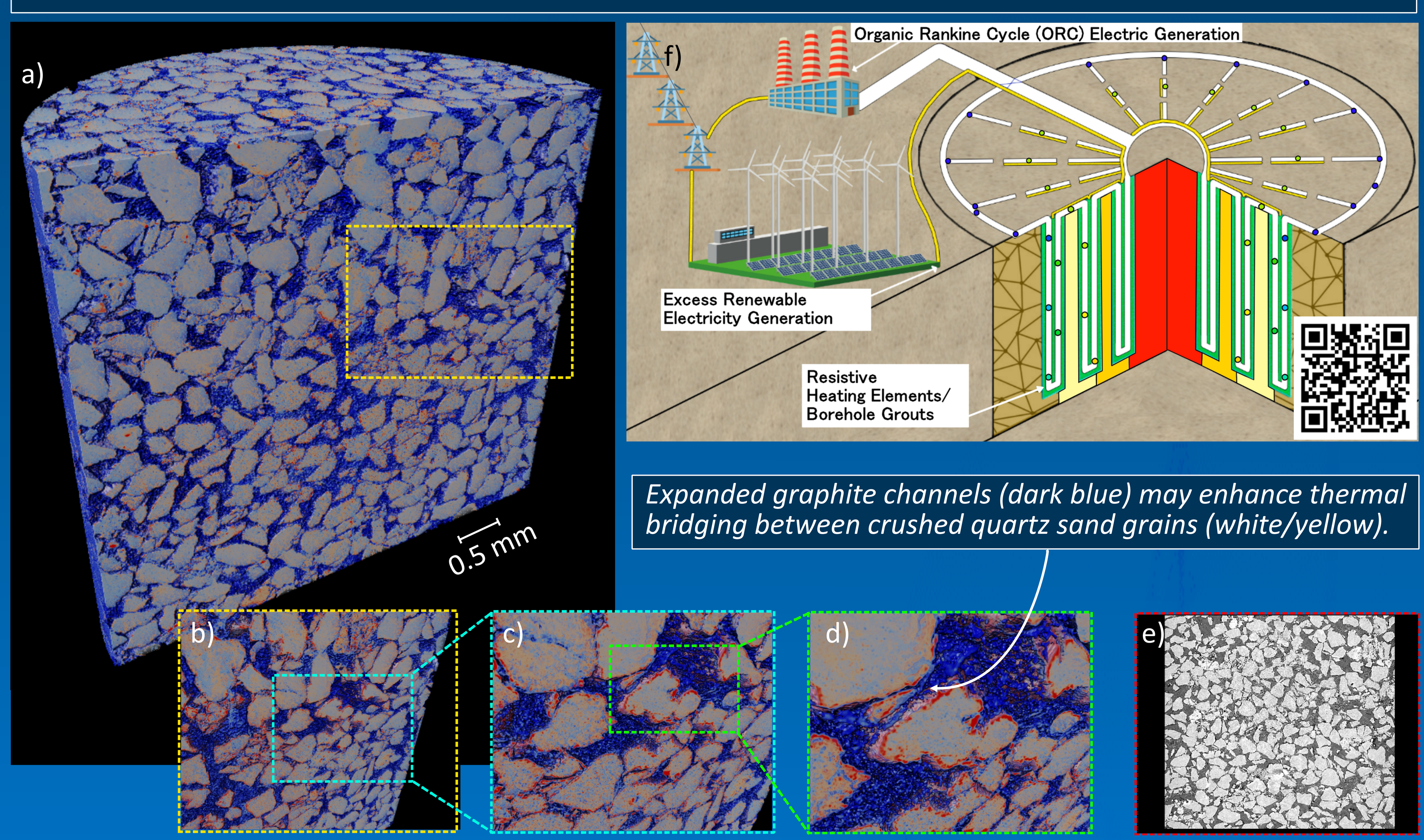




Geothermal and thermal energy storage applications

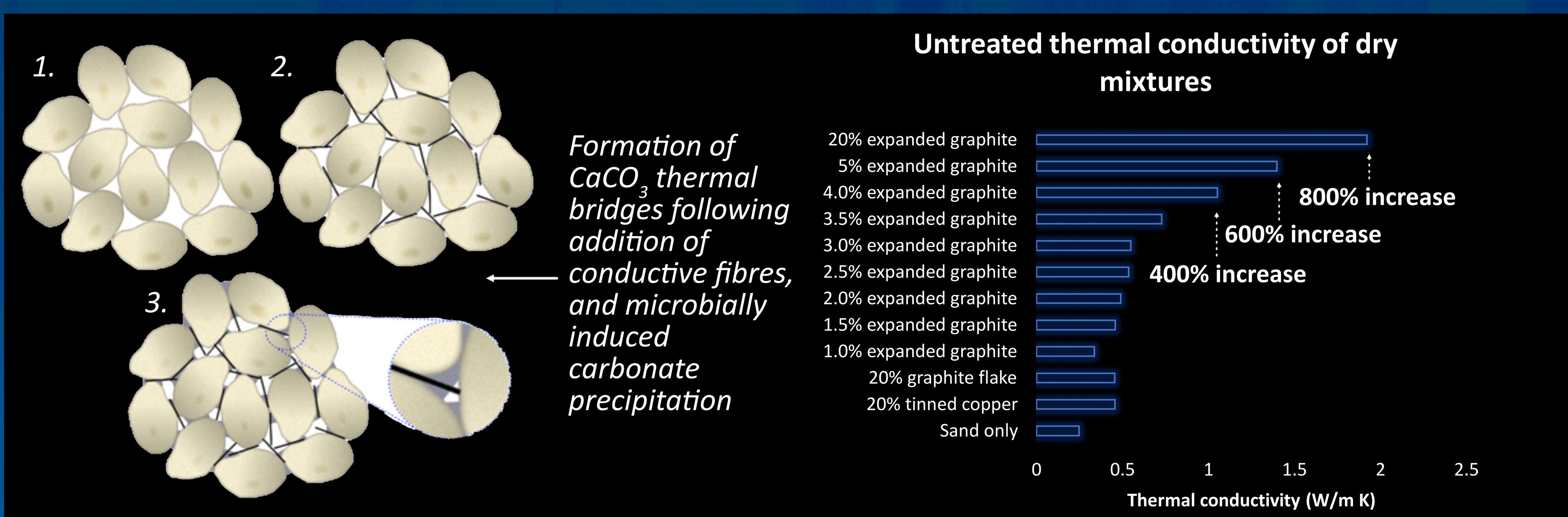
Improving the thermal properties of soils and well casings

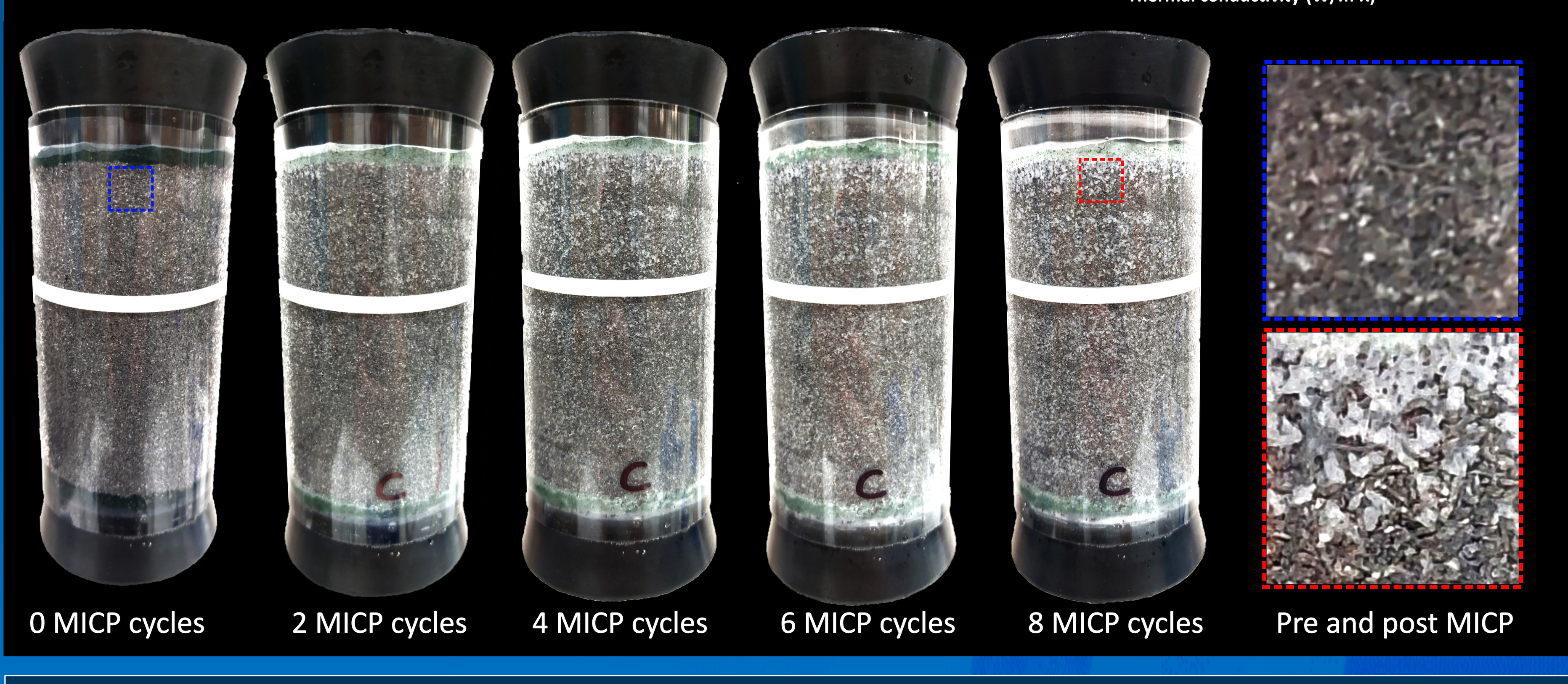
Precipitated minerals at the intergranular contacts between soil grains following microbially induced carbonate precipitation (MICP) can greatly increase the thermal conductivity of the ground [2]. We investigate enhancing this effect further with inclusion of highly conductive additives.



Expanded graphite channels (dark blue) may enhance thermal bridging between crushed quartz sand grains (white/yellow).

Crushed quartz sand (99 wt%) and expanded graphite (1 wt%) prior to MICP at various magnifications (a - d). e) a single greyscale projection and f) a theoretical borehole thermal energy storage system that utilises thermally enhanced grouts to store surplus renewable electricity. For the full video please follow the QR code.





Quartz sand (95 wt%) and expanded graphite (5 wt%) at various stages during microbially induced carbonate precipitation (MICP). The columns become progressively lighter as calcite is precipitated.

References: 1) Minto, J.M., El Mountassir, G., and Lunn, R. (2019). Micro-continuum modelling of injection strategies for microbially induced carbonate precipitation. *E3S Web of Conferences*. 92, 11019 2) Venuleo, S., Laloui, L., Terzis, D., Hueckel, T., and M. Hassan (2016). 'Microbially induced calcite precipitation effect on soil thermal conductivity.' *Géotechnique Letters*, 6 (1), pp.39-44.