# Enhancing fracture permeability due to in-situ mineral carbonation: an experimental investigation into reaction-driven cracking in ultramafic rocks


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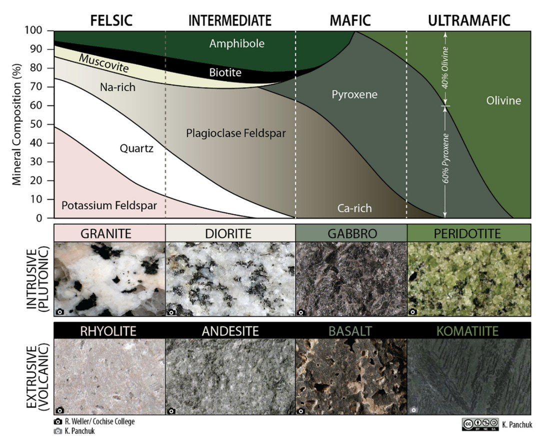
## Ultramafic rock: $CO_2$ storage & economic mining applications

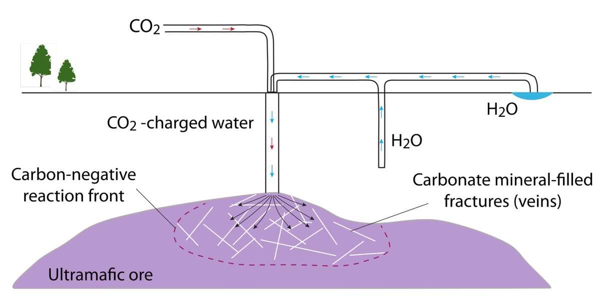
**Ultramafic formations are compelling sites for $CO_2$ storage:**

- Mineral constituents (olivine, brucite) are energetically favorable for reaction with $CO_2$ — *permanent* mineral trapping
- Rich in critical minerals
- Reaction kinetics may increase porosity & fracture networks and decrease strength
- Reaction kinetics show increase in solid volume as much as 40% — reaction-driven cracking
- Altered ore is weaker & reduces extraction costs
- In-situ injection offers orders of magnitude greater storage capacity



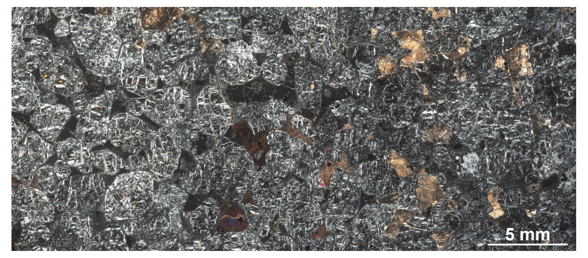

***Questions driving this work:***

- *How can we leverage chemo-poro-mechanical processes to sustain reaction at field conditions?*
- *How does $CO_2$ sequestration change the mechanical strength of the subsurface?*



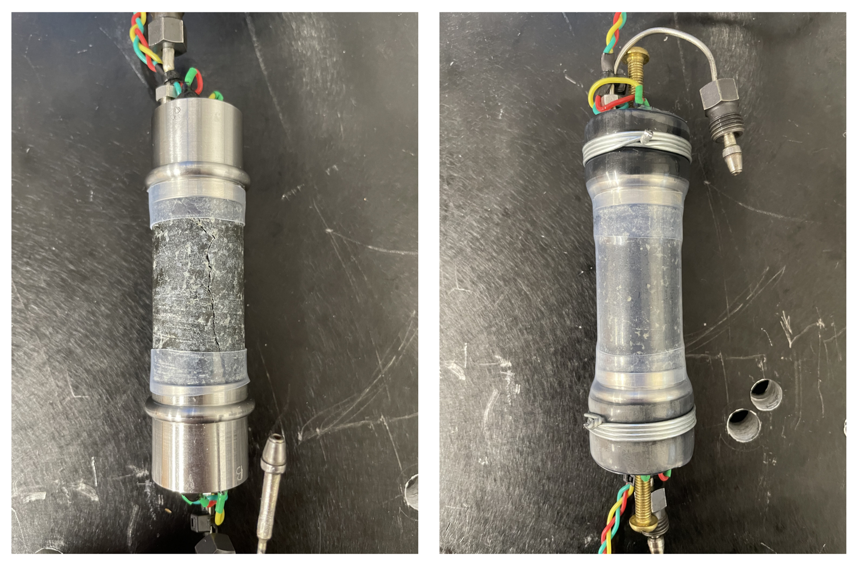

## Simulating field conditions and kinetics in the laboratory

- Laboratory experiments to investigate the complex interplay between poromechanics and kinetics in the subsurface.
- *Develop methods and techniques for enhancing pore/fracture network permeability* — increasing $CO_2$ storage potential.
- We present a novel experimental apparatus that injects carbonated water into ultramafic samples for several months.

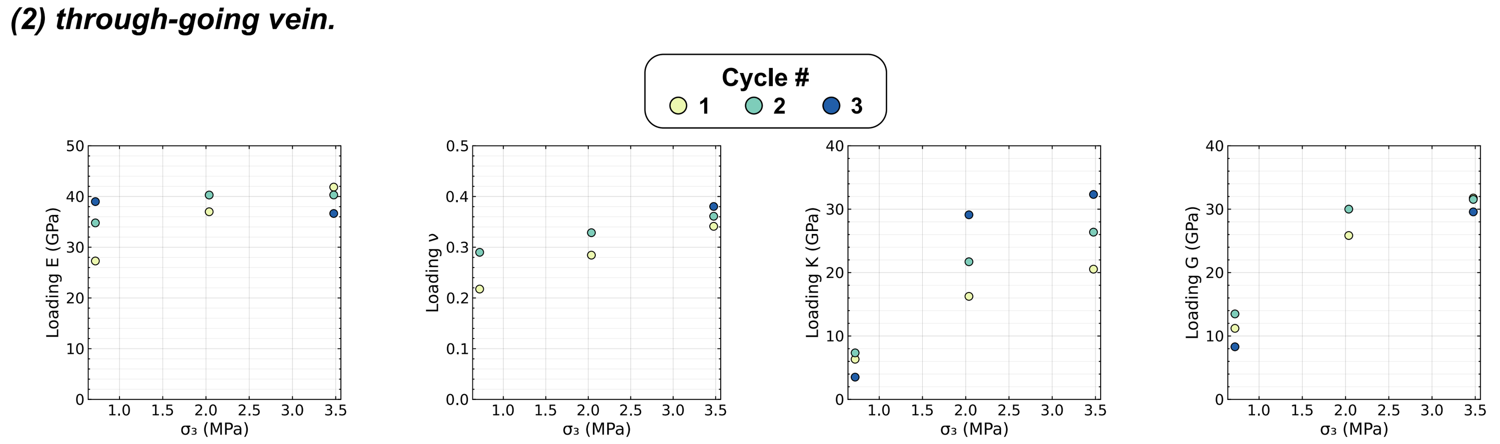



## Ultramafic rock characterization & sample preparation

**(a)** Ultramific samples were cored to 25.4 mm diameter and 45 mm long from larger rocks. A tensile fracture formed along the length of the core sample. Then, the sample was secured between both end caps.
**(b)** Teflon tubing was placed around the core assembly then shrunk. Lacing wire on each end cap ensured permanent sealing. The sample configuration was attached to the top fixture of the pressure vessel before sealing.

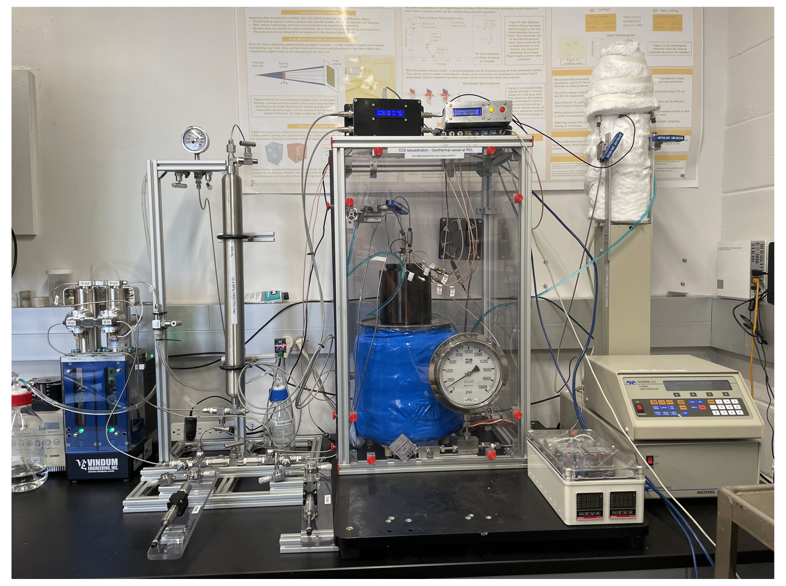


***Two experiments were conducted using samples with: (1) pre-existing fracture and (2) through-going vein.***

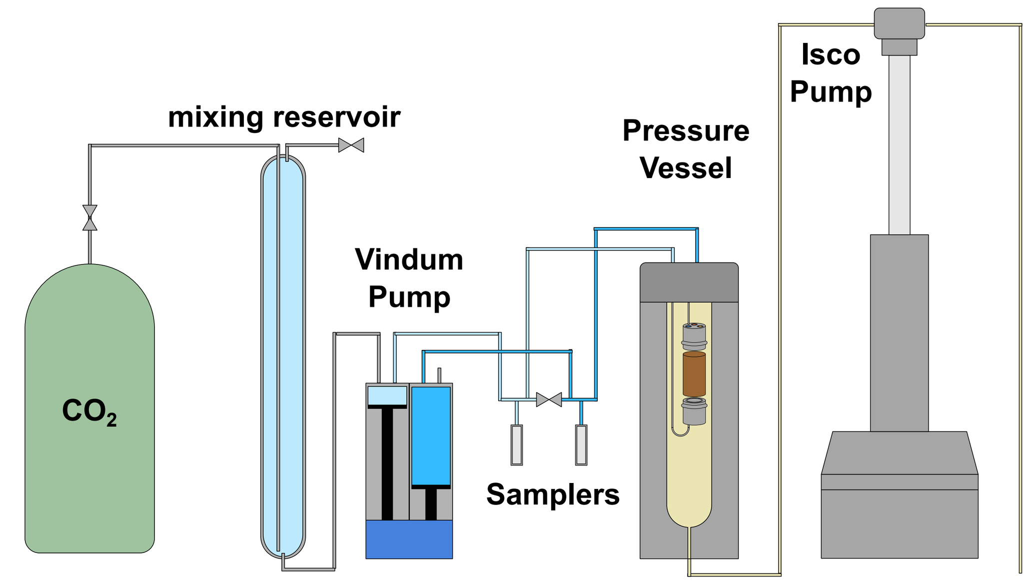



Measurements of elastic moduli and Poisson ratio for a 25.4 mm diameter ultramafic samples. The samples were sealed and fixed inside of triaxial apparatus and underwent isotropic compression and deviotoric stress tests with loading/unloading cycles at different confining pressures, $\sigma_3$.

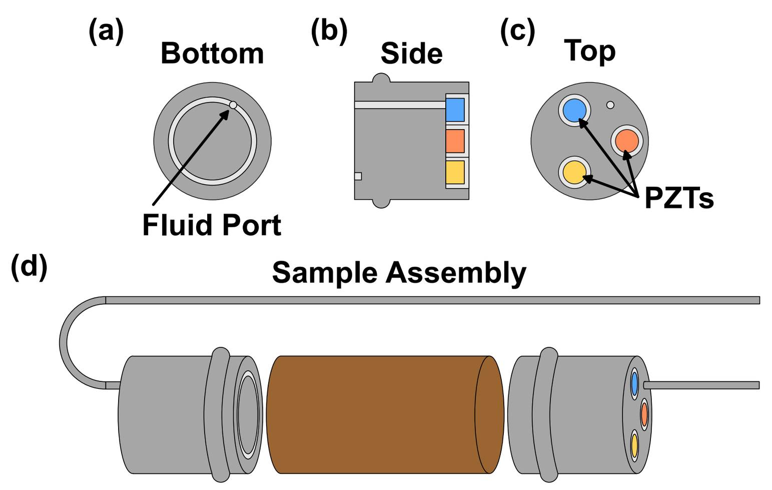
## Novel experimental injection apparatus



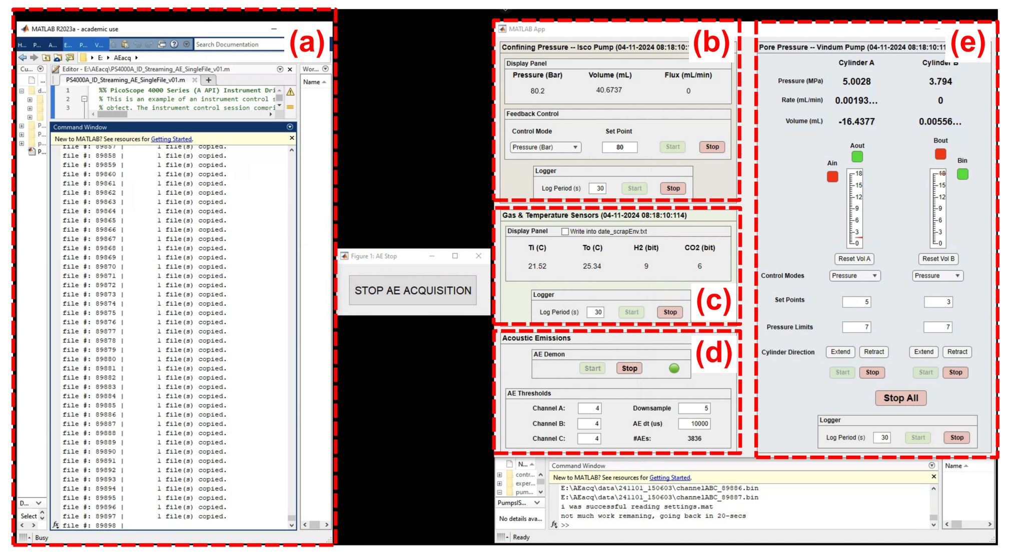
Experimental apparatus developed for this project. There are 3 novel aspects about this custom-built apparatus: (1) a pressure vessel with temperature control, (2) continuous acquisition at 10 MHz of acoustic emisions, and (3) long-term stability on the order of months.




Schematic of injection apparatus. **(a)** $CO_2$ cylinder and mixing reservoir carbonate water before injection. **(b)** Vindum pump with independently controlled cylinders injects carbonated water. **(c)** Fluid manifold with collection syringes that allow for sampling pressurized inlet/outlet fluids. **(d)** Isco pump maintains constant hydrostatic pressure inside of pressure vessel.




**(a)** Bottom face of end cap has a through-fluid port and circular groove to evenly distribute flow. **(b)** End cap side view, showing position of embedded piezoelectric transducers (PZTs), colored. **(c)** Orientation of PZTs shown in top view of end cap (P, $S_1$, $S_2$). **(d)** Schematic of sample assembly.



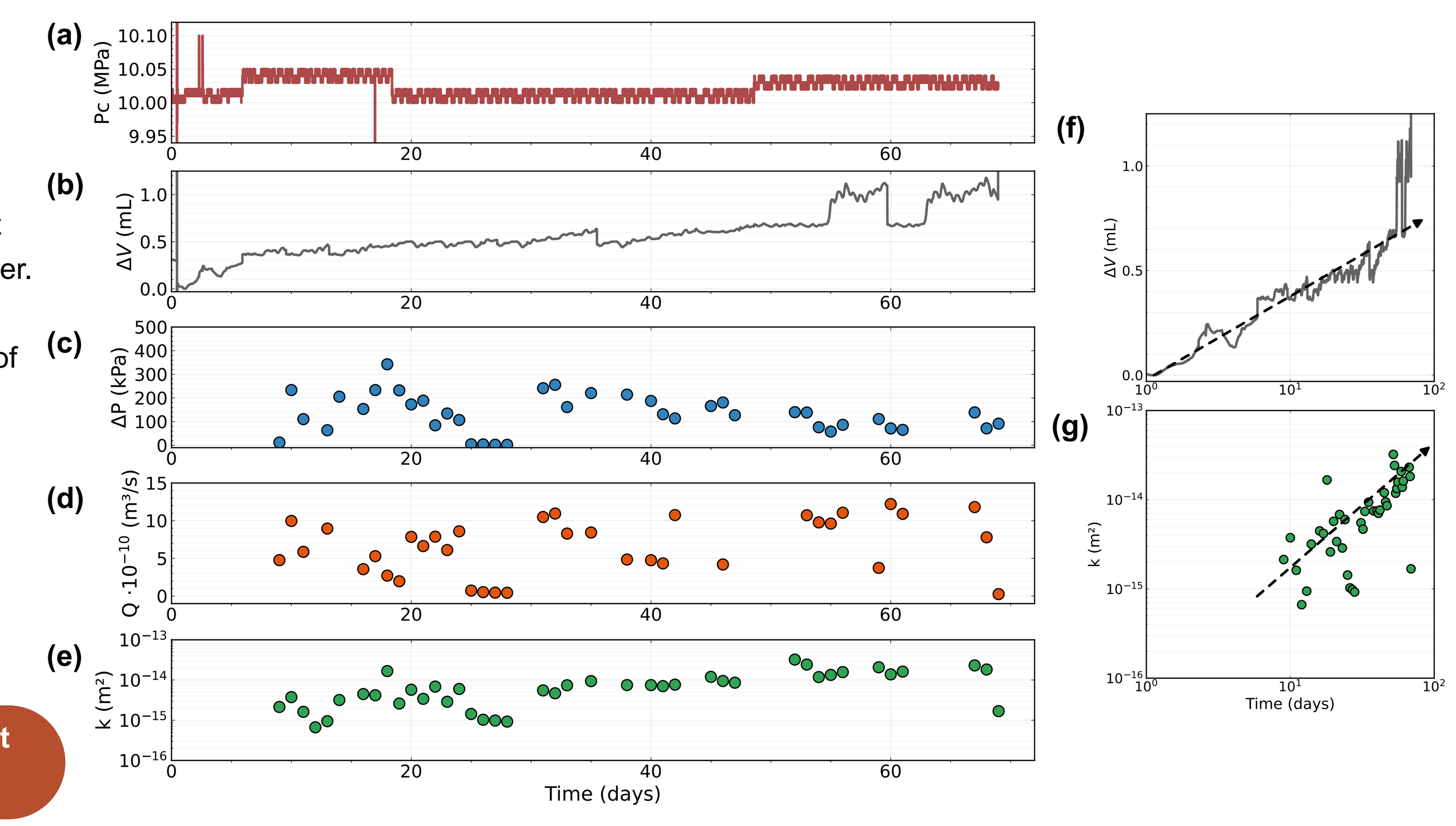

Software was developed in-house to control apparatus. **(a)** Continuous acquisition from Picoscope at 10 MHz to record acoustic emissions. Panels to control and record from: **(b)** Isco pump for confining pressures, **(c)** temperature and environmental sensor, **(d)** initiate background analysis for acoustic emissions, and **(e)** Vindum pump for injection.

## Long-term experiment shows trend in permeability enhancement

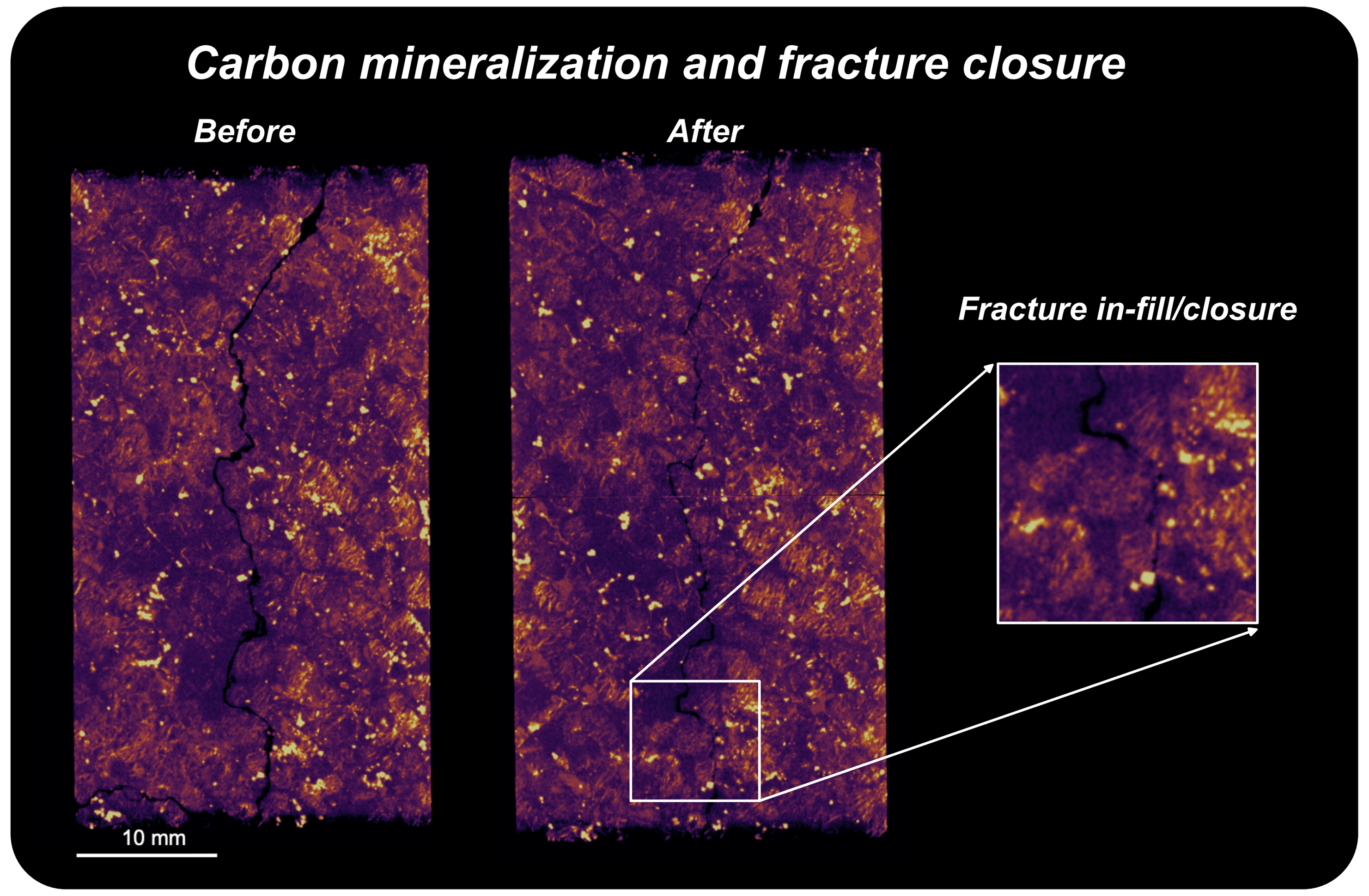
The first experiment, using a pre-fractured ultramafic sample, lasted for 70 days, demonstrating one of the main goals — long-term stability and time-scales relevant to field injection studies.

**(a)** Confining pressure Pc is maintained at a constant 10 MPa. **(b)** Volume change of confining pump cylinder. **(c)** The inlet pressure was kept constant at 2.3 MPa. **(d)** The outlet cylinder was maintained at a flow rate of ~ 5*$10^{-10}$ $m^3/s$. **(e)** Permeability during steady-state flow ($Q_{in}$ = $Q_{out}$, within 1%) during the experiment. **(f)** and **(g)** show the relative change in confining cylinder volume and permeability, respectively as a function of log-time.

**Take-away: systematic permeability enhancement of nearly 100x over 70 days due to dissolution.**

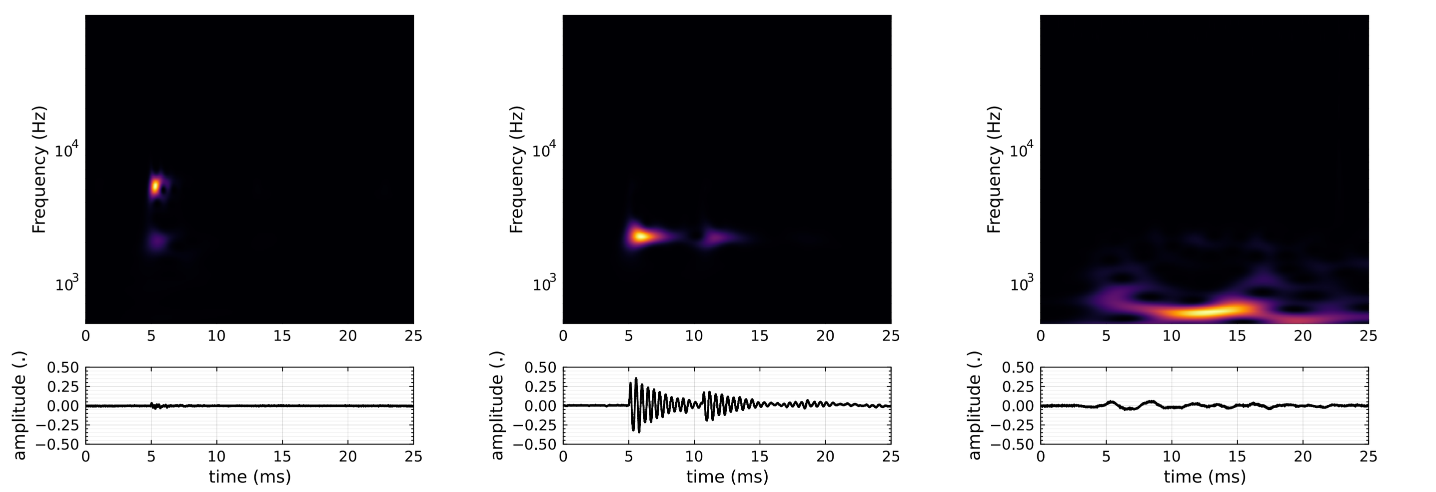



## Carbon mineralization and fracture closure




2D slices from micro-CT volumes of the fractured sample before and after the 70 days-long experiment. Darker colors correspond to minerals with lower density and brigher colors to higher density. Though chemical analysis is on-going, the main observation is fracture in-fill from reaction along the fracture plane — more prevalent at outlet side.

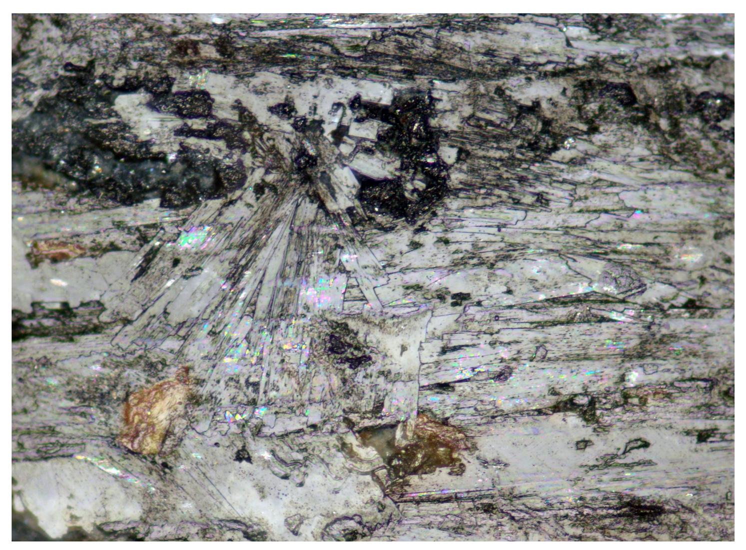
## Acoustic emissions attributed to fracture deformation




Gallery of acoustic emissions recorded from 2nd experiment. Range of dominant frequencies in acoustic emissions recorded during the experiment. These are primarliy attributed to vein/fracture deformation rather than reaction-driven cracking. Low frequency events could be linked to fluid-induced mechanisms.

## Conclusions

- **We have built a new injection apparatus capable of injecting reactive fluids into rock cores over long periods of time — months**
- **100x permeability enhancement over 70 days-long experiment**
- **Dissolution dominates — eroding major flow pathways, despite some fracture in-fill**
- **Carbonate precipitation is minimal, but future experiments will use samples with enhanced porosity and cation-rich fluids**



**Evidence of nesquehonite ($MgCO_3 \cdot 3H_2O$) precipitation. Field of view is ~2 mm.**