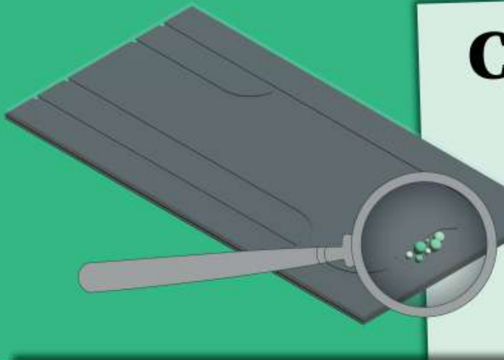
Carbon capture and storage rocks!

with

... but how fast is it?



We are building a new microfluidic platform to find out!

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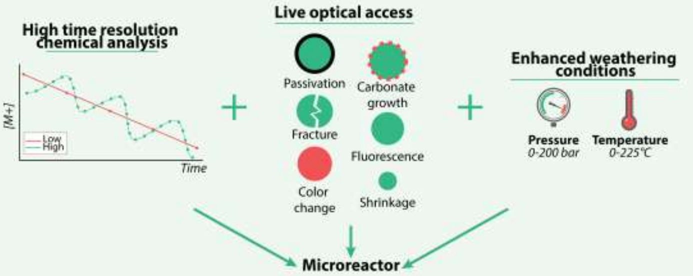
Introduction and goal

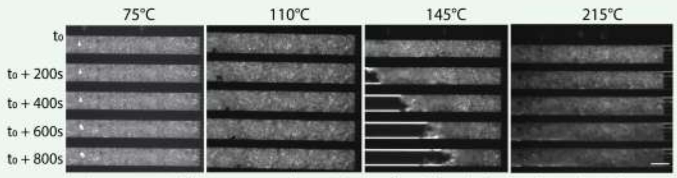
We are building a platform that combines **fast chemical sampling** with **live optical access** to study **mineral dissolution rates** under enhanced weathering conditions. The platform consists of a microreactor and an accompanying setup and may be used to study phenomena like non-stoichiometric dissolution, (pre-passivation) dissolution rate, secondary/passivation layer growth kinetics, precipitation, and transport regimes. Ultimately, this information should inform enhanced weathering strategies regarding their expected rate and efficacy under specified conditions.



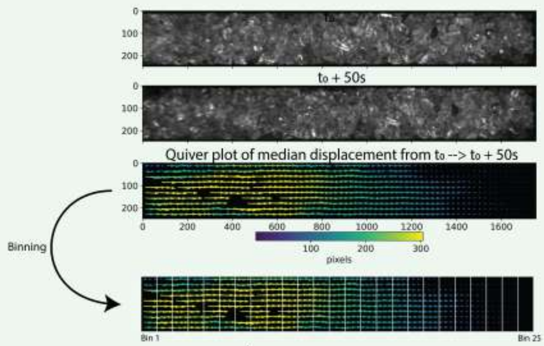
Optical observations

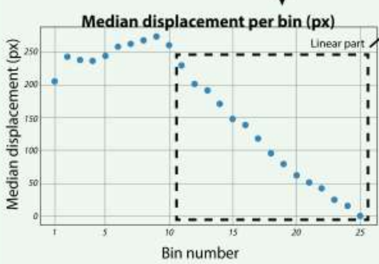
Application of an optical flow algorithm to determine dissolution rate

Measuring dissolution rates in packed-bed reactors is often complicated by mass transport limitations, requiring careful and time-consuming calibration of the flow rate [1]. Alternatively, we explore whether the dissolution rate can be measured optically. To this end, we make time-lapses of the particle bed during dissolution. For each image pair in the time-lapse, the median displacement per pixel is calculated using the Gunnar-Farnebäck optical flow algorithm. We then examine how the median flow velocity varies with position in the reactor and temperature.

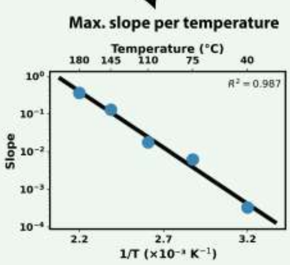


Time lapse images. Each frame is 200 seconds apart. The flow is from left to right. The particles are olivine (d_{50} = 50-70 µm) and are dissolving in 0.1M HNO_3 at a flow rate of 100 µl/min.





Measuring the slope of the linear regime
Plotting the (maximum) slope of the linear regime for each temperature

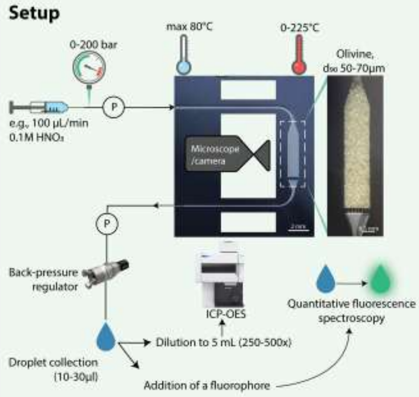


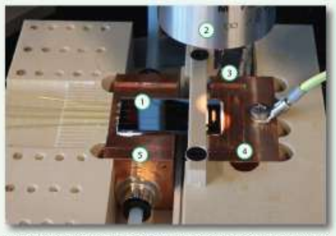
We find excellent agreement between the slope of the displacement and the temperature following an exponential fit, as expected from the Arrhenius equation correlating dissolution rate with temperature. Future research will couple the optical observations with chemical analysis and mathematical modelling to confirm this optical method of measuring dissolution rates.

Chip fabrication and setup

Fabrication

Setup





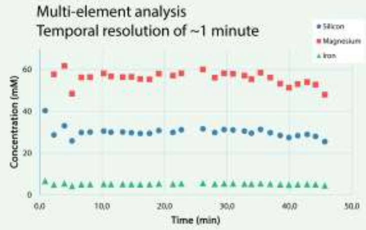
The microreactor (1) in the setup. A microscope objective (2) with a camera enables live observation of the reaction chamber in reflactance mode. The temperature is controlled via a PID-controlled cartridge heater (3) which heats the copper block (4) under the reactor area. The inlet area (5) is temperature controlled with a cooling fluid.

Chemical analysis

To validate the dissolution rate measured by optical flow, we measure the concentration of ions coming out of the microreactor. We sample the effluent with a temporal resolution of ~15 seconds and quantify ion concentrations using ICP-OES and fluorescence spectroscopy.

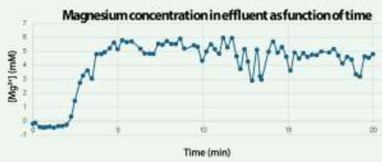
ICP-OES

Multi-element analysis
Temporal resolution of ~1 minute

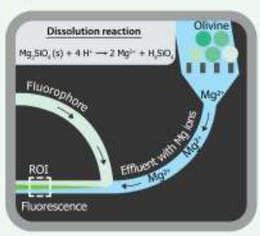


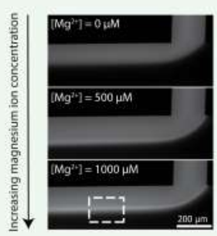
Fluorescence spectroscopy

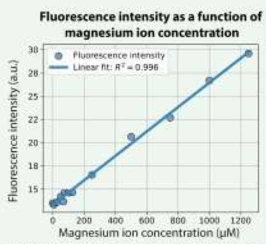
Magnesium concentration analysis
Temporal resolution of ~15 seconds



To improve temporal resolution even further, we are developing a method to measure the concentration of Mg^{2+} in-line within the microreactor using fluorescence microscopy.







Left | Working principle. Olivine particles are trapped in the reactor area where they dissolve in an acidic, aqueous flow, releasing magnesium ions according to the dissolution equation. A second flow containing a magnesium-sensitive fluorophore is introduced parallel to the first. On the interface between the two fluids, diffusive mixing takes place, resulting in a fluorescence intensity proportional to the magnesium ion concentration.
Center | Fluorescence intensity on the interface increases for increasing [Mg^{2+}].
Right | Linear relationship between the maximum fluorescence intensity on the interface and [Mg^{2+}] using standard magnesium chloride solutions.

In the future, we validate the optical flow dissolution rate measurements by comparison with ICP-OES. Furthermore, we continue to work on our dream goal: integrating all techniques into one system, revealing (hopefully) lots of new information about mineral dissolution kinetics which inform enhanced weathering models.

Conclusion

- Microreactor as a novel tool to measure dissolution rates optically and chemically at high temperatures and pressures
- Optical flow algorithm to measure dissolution rates optically
- 15-second temporal resolution for chemical dissolution rate measurements
- In-line continuous magnesium sensing by fluorescence microscopy

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