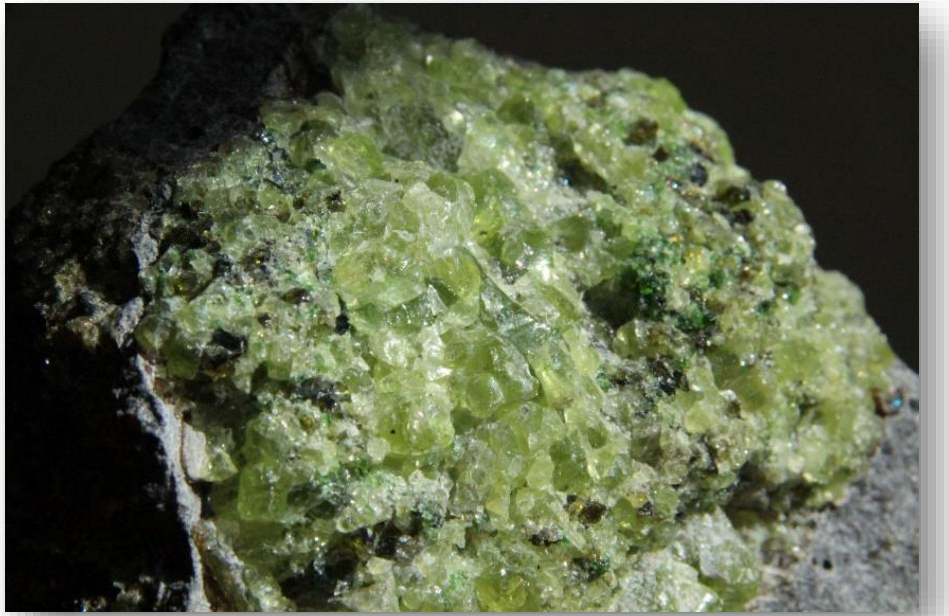
Hydrogène Orange: expériences et perspectives

F. Osselin

Image: WHOI

Natural Hydrogen

- **Abiotic oxidation of iron:** $2FeO + H_2O = Fe_2O_3 + H_2$
- **Radiolysis**
- **Magmatic degassing**

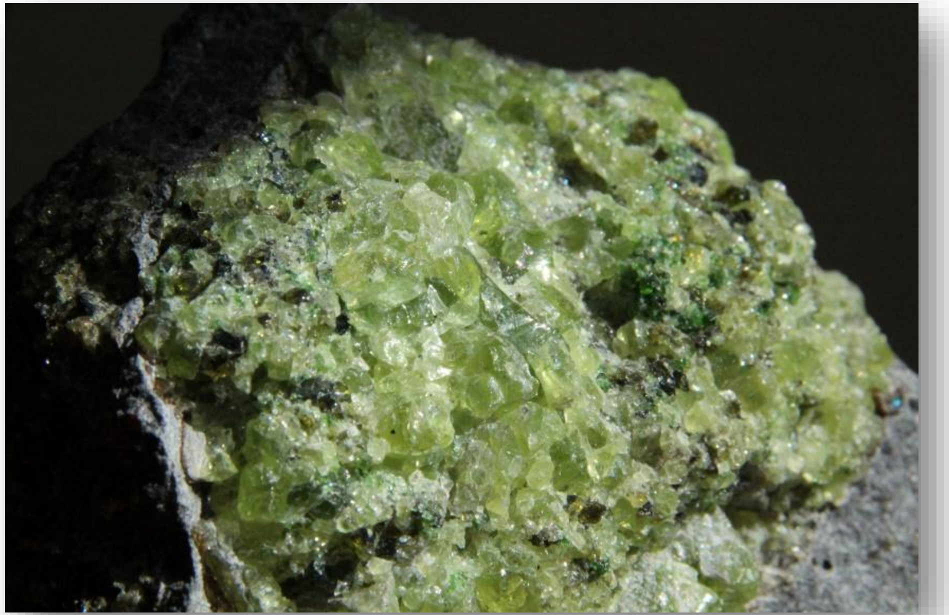


Peridotite

- **20Mt escaping every year from the subsurface to the atmosphere** (Zgonnik 2020)
- **10^{20} kg of peridotite on the first 7km of Earth** (Kelemen 2008)
  - ✓ **1 kg_{H2}/m^3, potential 10^8Mt**

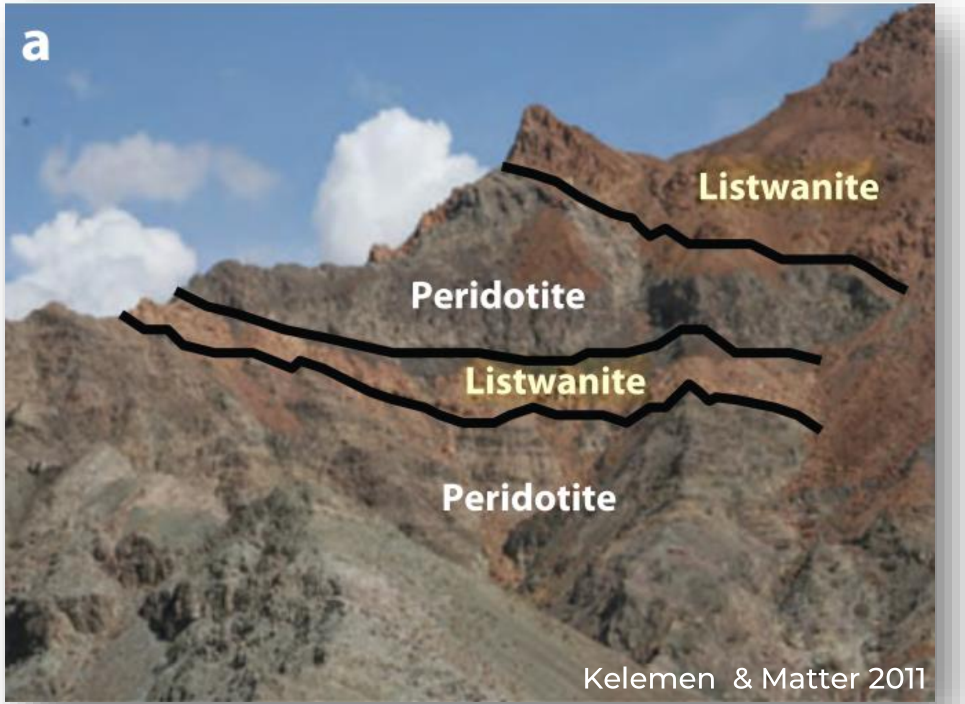
Natural Carbonation

Peridotite



$+CO_2$

Listwanite: geological formation resulting from the extensive carbonation of peridotites



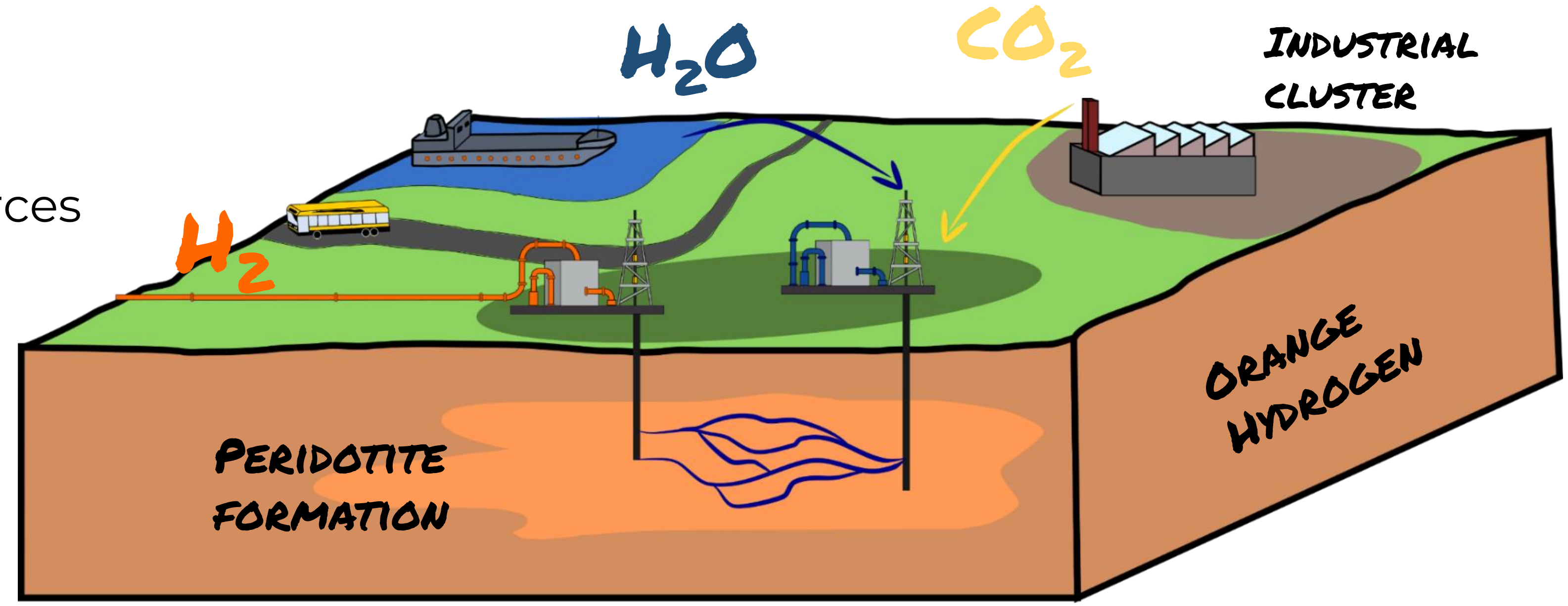
$$(CaO, MgO) + CO_2 = (Ca,Mg)CO_3$$

99,9% of total C stored as carbonates

Orange Hydrogen: Stimulated Natural H_2

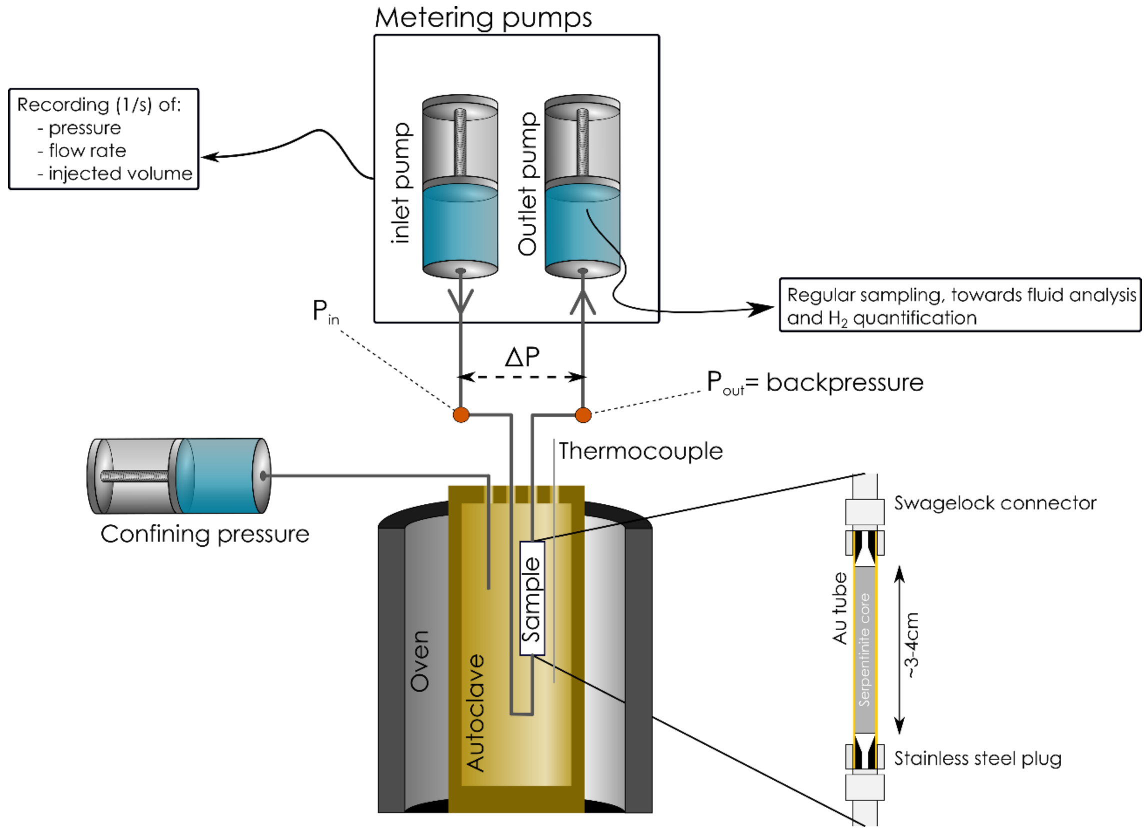
- **Stimulated production**
  - ✓ 100 000 years of H_2
  - ✓ Controlled production rate
  - ✓ Simplified exploration
  - ✓ No excavation/mining
  - ✓ No stress on freshwater resources

- **Combination of CO_2 and H_2**
  - ✓ Economically more robust



- ✗ More complicated process
- ✗ Requires injection & fracking
- ✗ Not « renewable »

Orange Hydrogen in the lab



Osselin et al. GCA, 2022

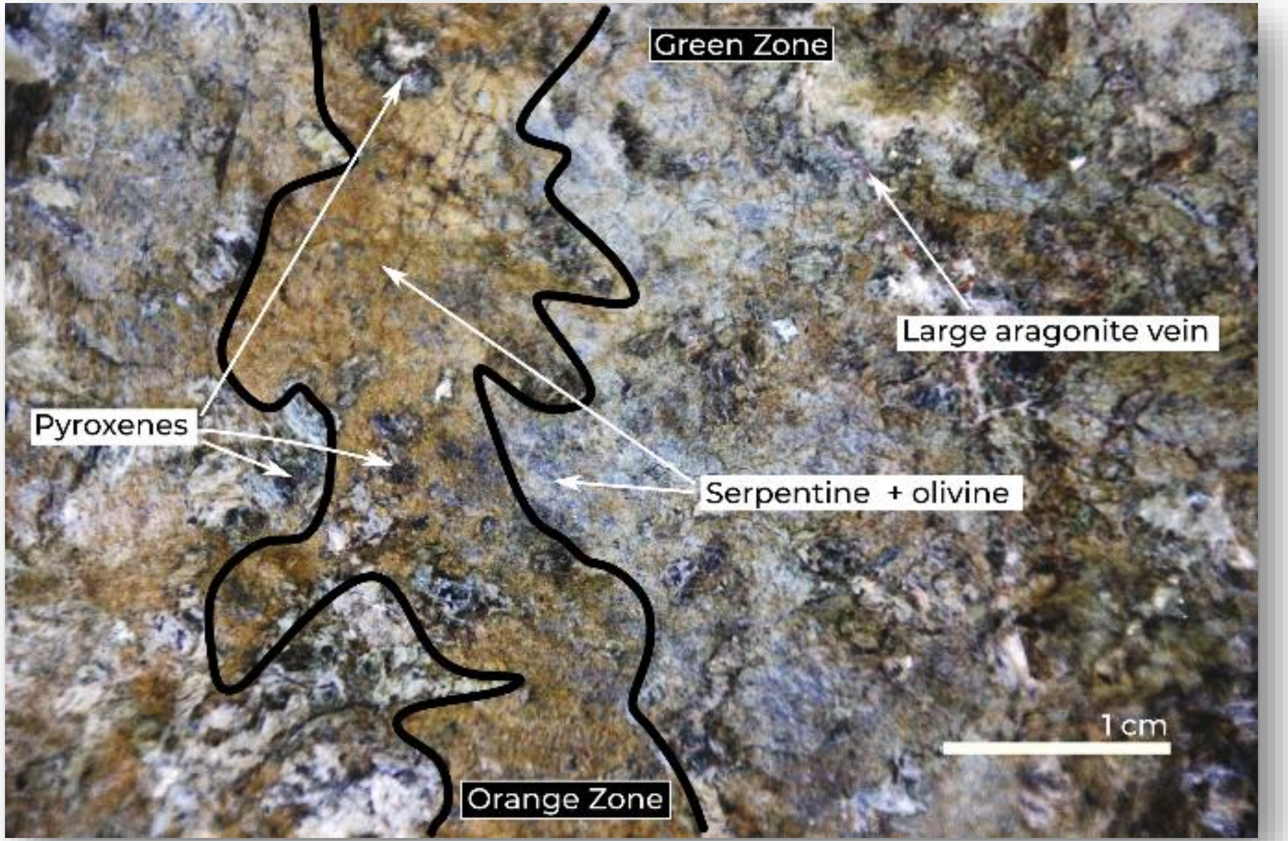
Reactive percolation experiments

Cores 5.6mm dia. – few cm long

P < 500 bar – < 400°C

F.Osselin

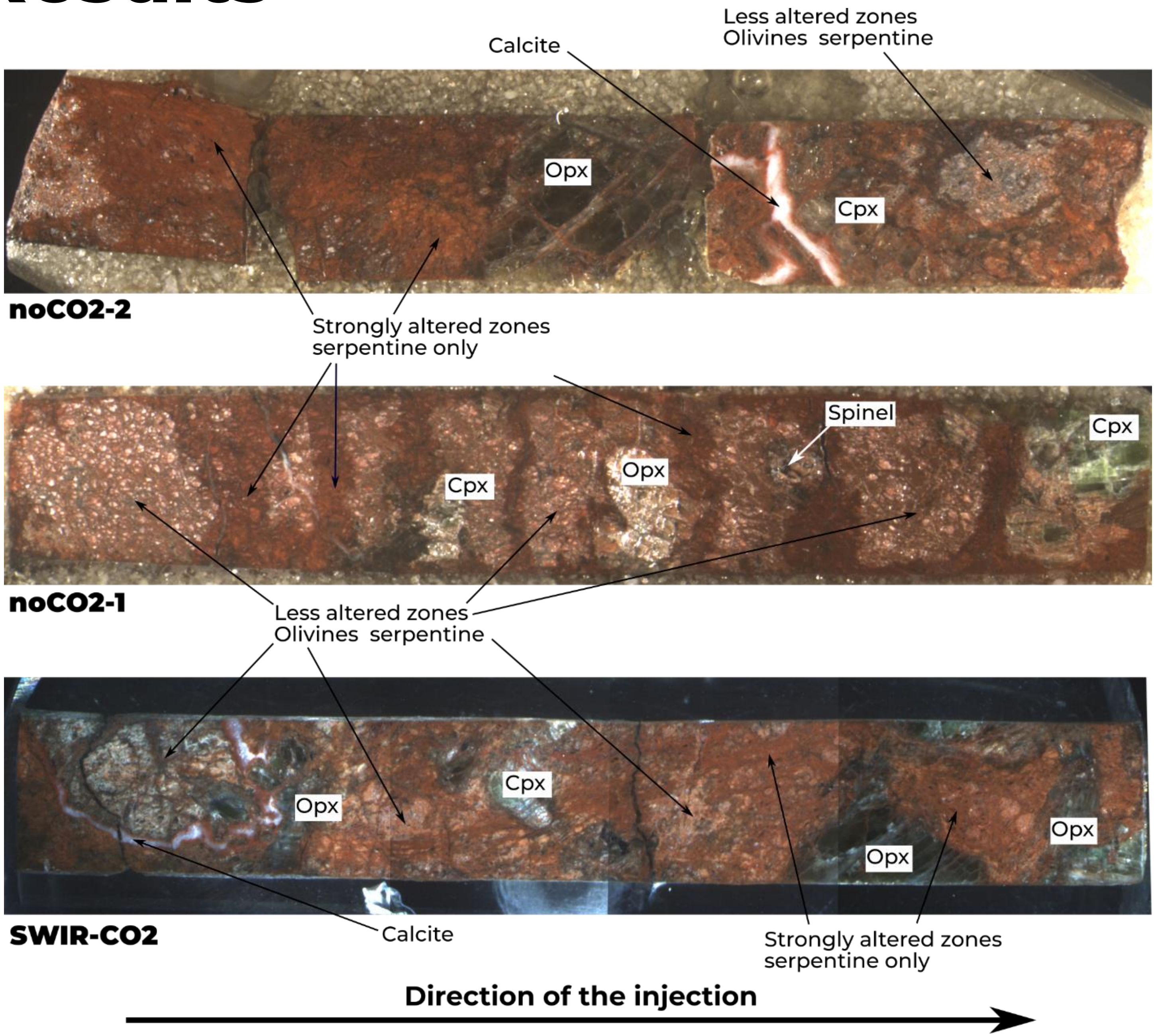
Orange Hydrogen in the lab



Natural Serpentinite:
50% Serpentine
20% Opx
11% Cpx
13% Olivine
5% Aragonite
1% Spinel

Injection at 280°C
2 experiments with pure NaCl
1 experiment with NaCl+$NaHCO_3$

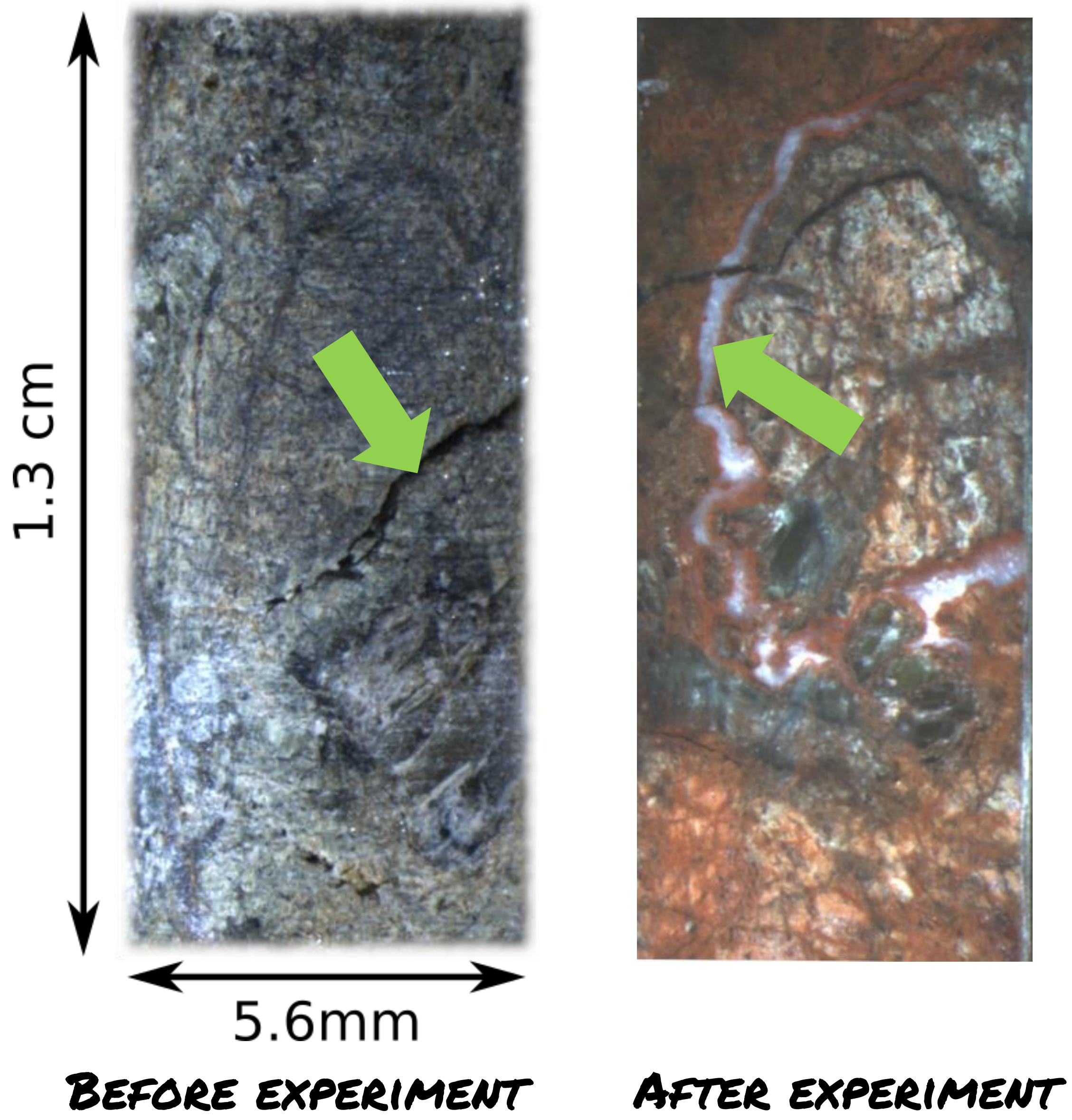
Results



General decrease of carbonates

General increase of carbonates

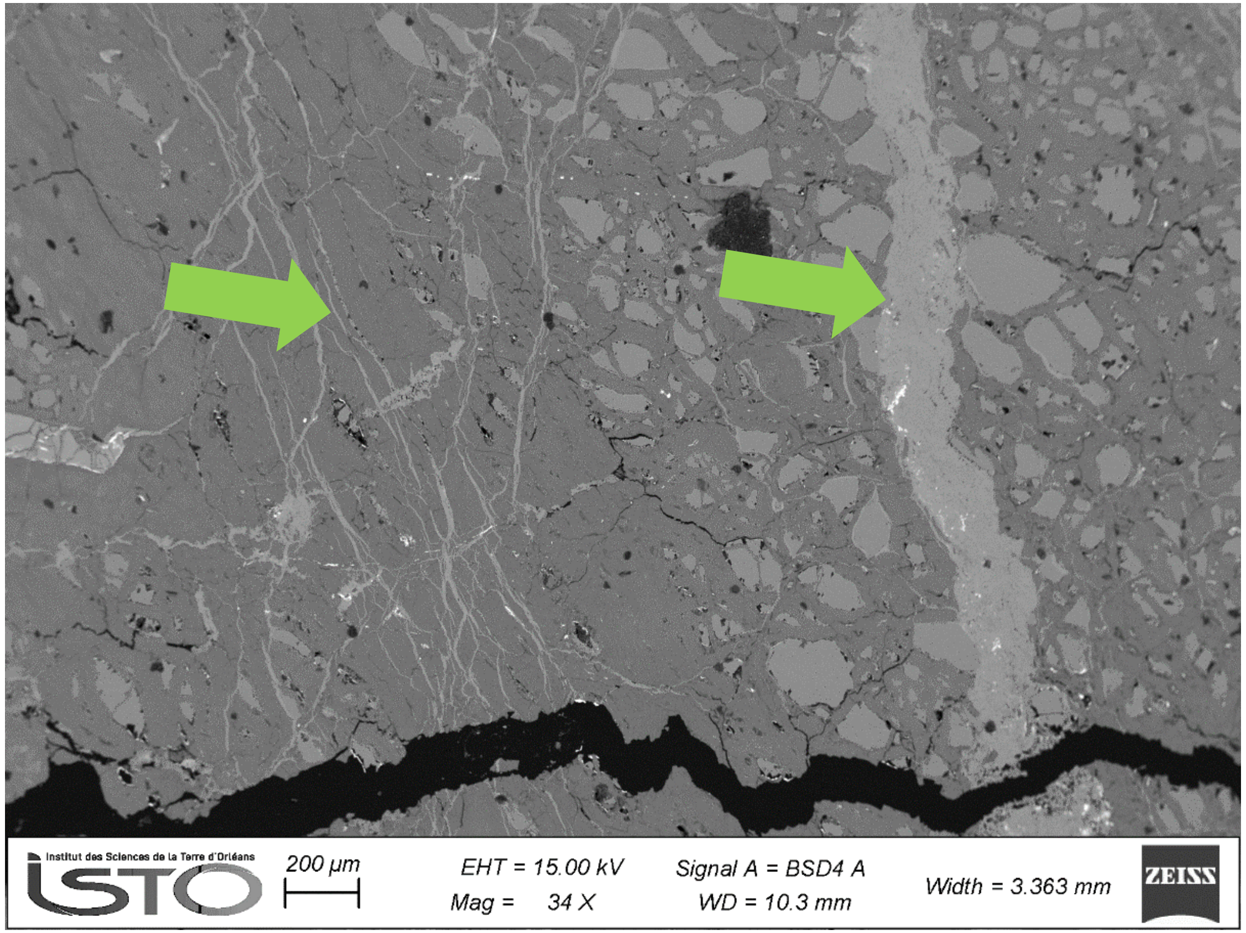
Results – Carbonate precipitation



CO_2

Initially opened fractures get filled with calcite

Results – Carbonate precipitation

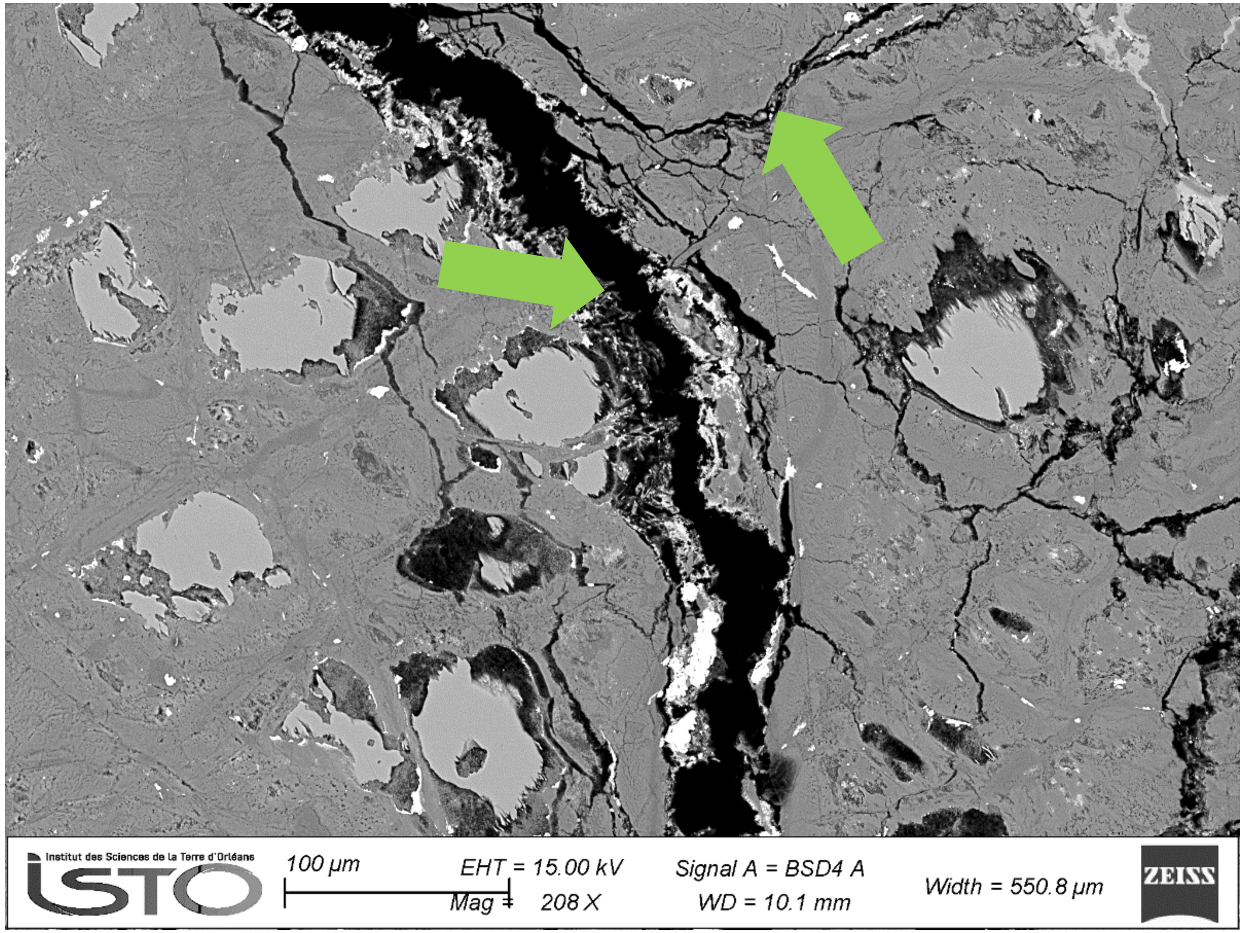


CO_2

Initially opened fractures get filled with calcite

Secondary percolation paths also appear clogged with calcite (SEM)
Multiscale precipitation

Results – Carbonate precipitation



CO_2

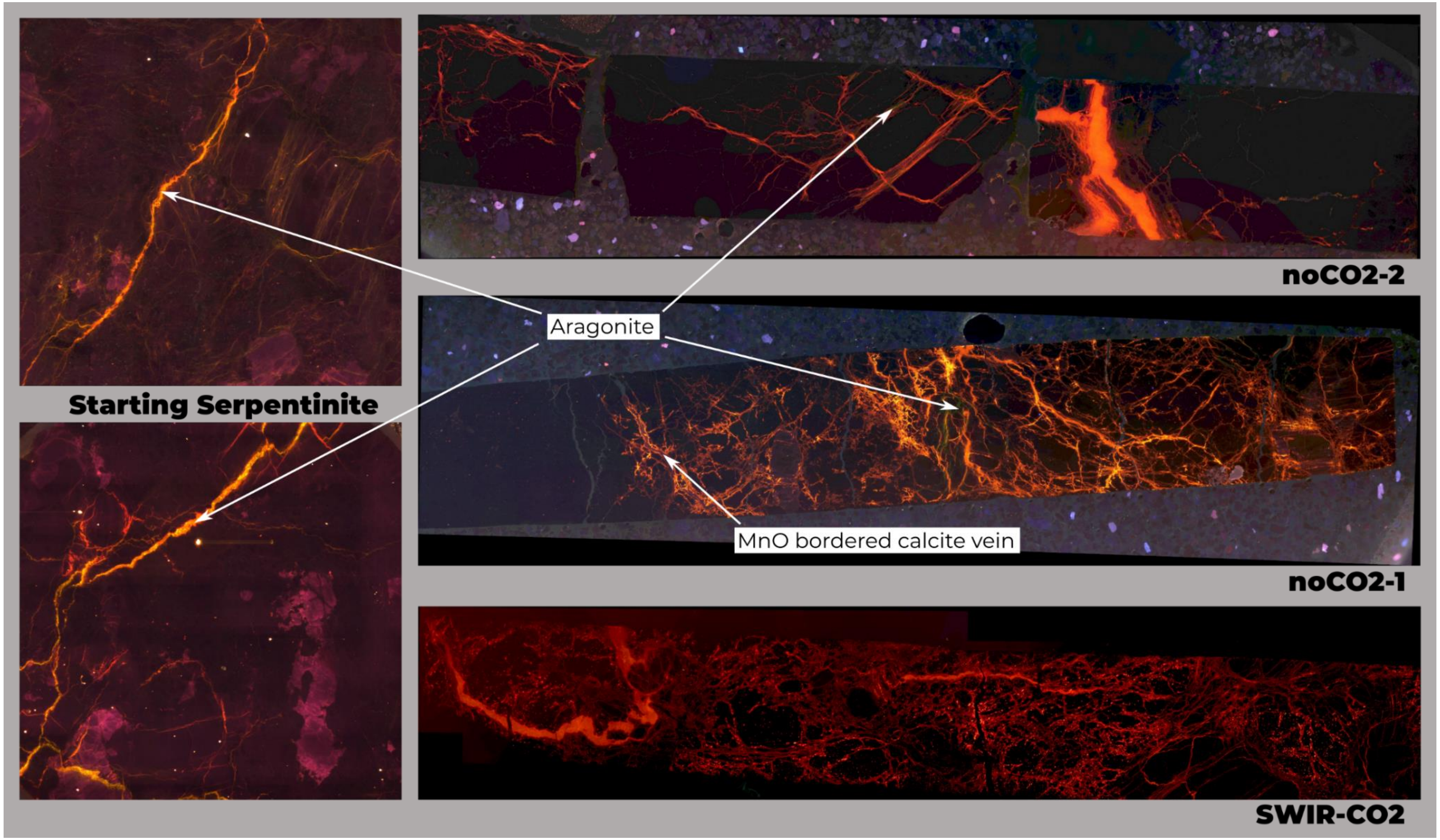
Initially opened fractures get filled with calcite

Secondary percolation paths also appear clogged with calcite (SEM)
Multiscale precipitation

$noCO_2$

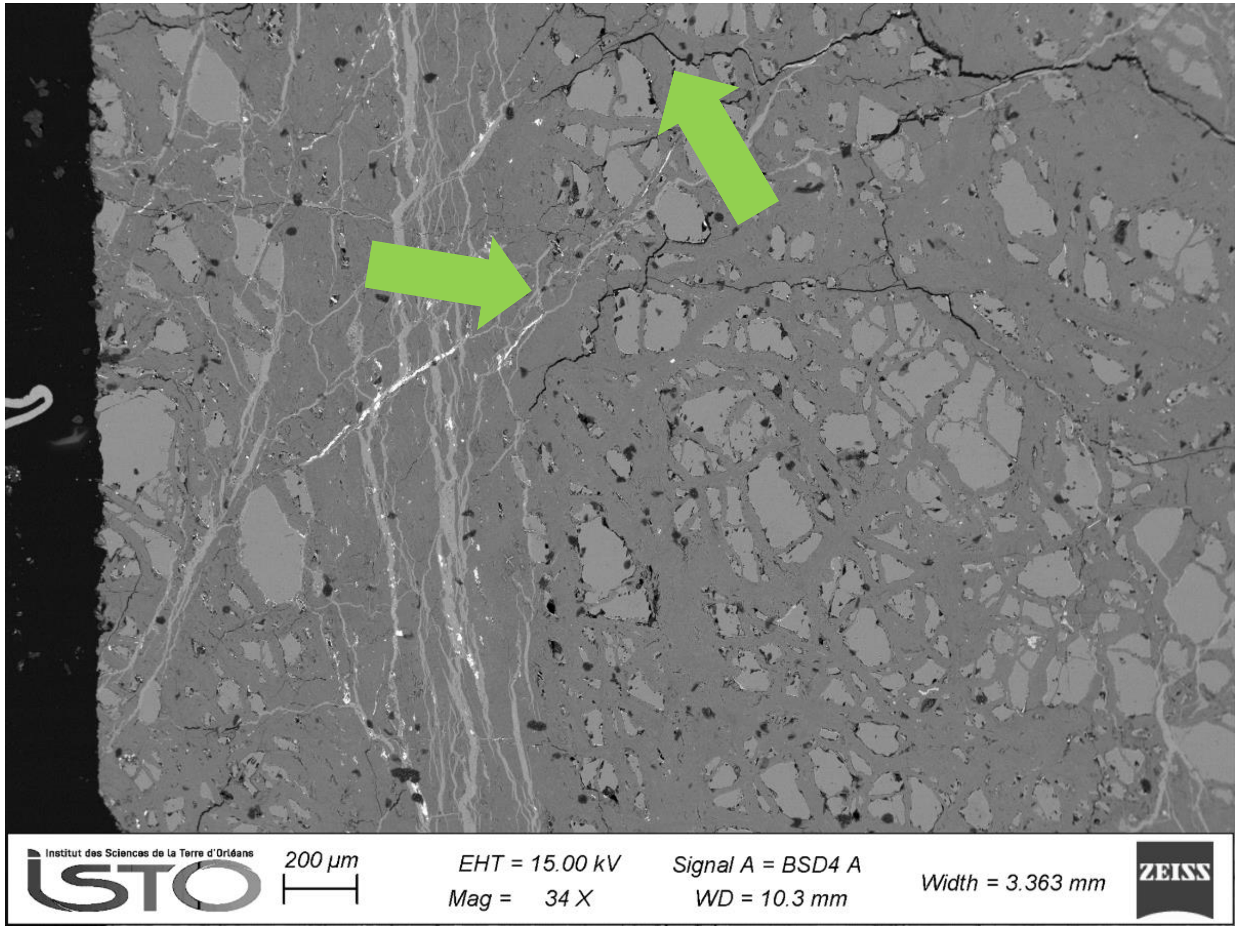
Aragonite veins get emptied on all scales

Results – Carbonate precipitation



Much denser and brighter network of carbonates – MnO pollution from inox corrosion

Results – Silicate alteration

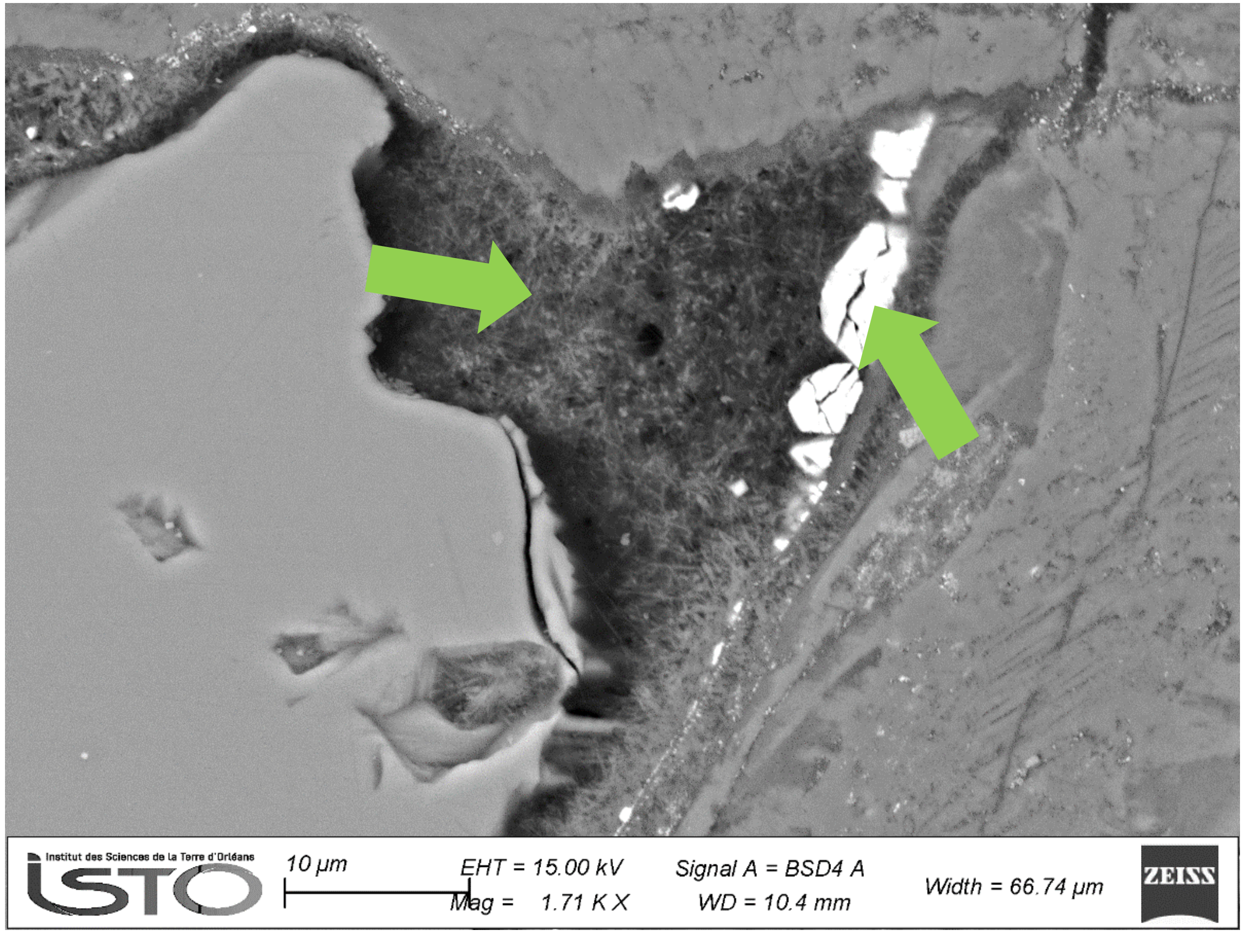


CO_2

Complete replacement of olivines by serpentine mesh in main and secondary percolations paths

Absence of olivine alteration in low flow zones

Results – Silicate alteration



CO_2

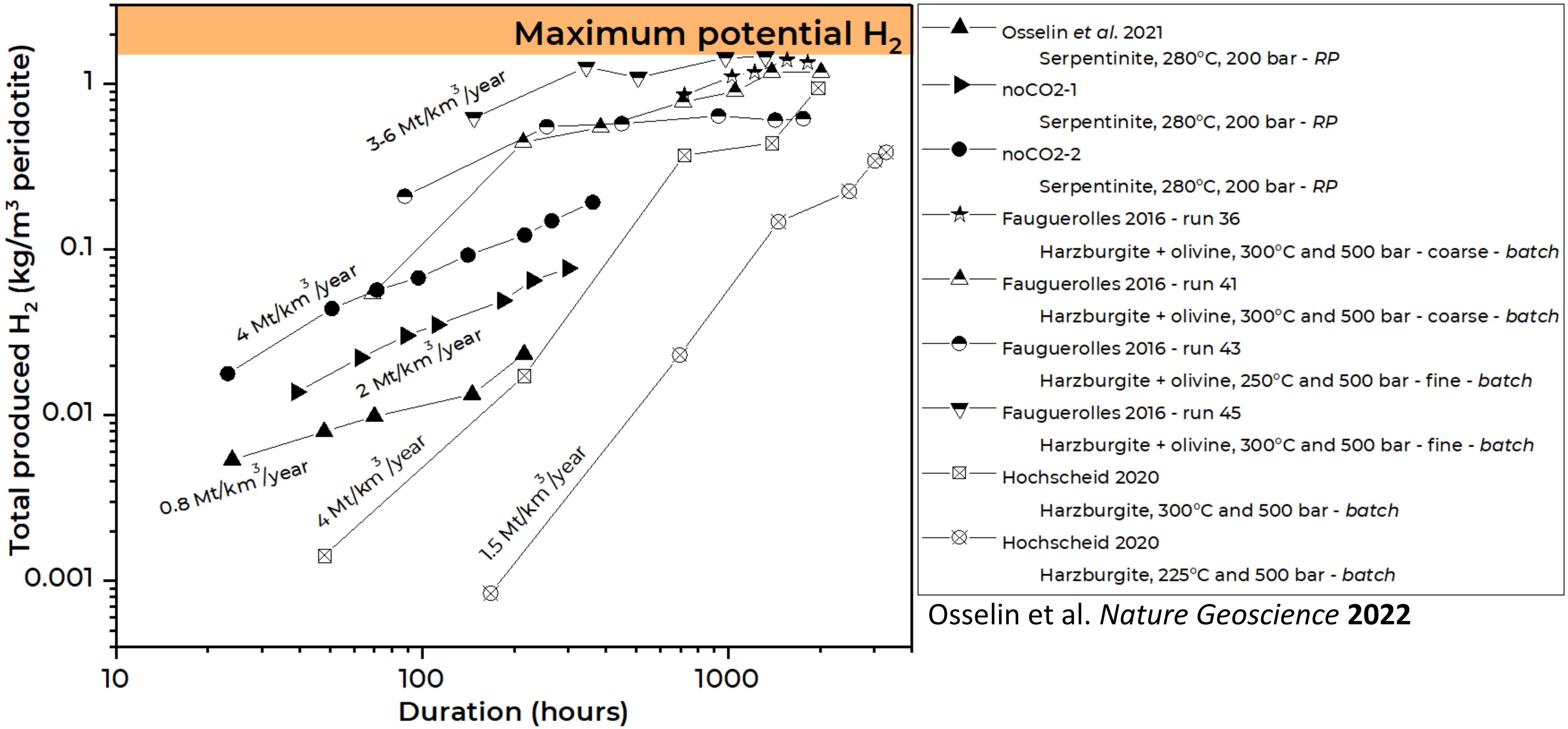
Complete replacement of olivines by serpentine mesh in main and secondary percolations paths

Absence of olivine alteration in low flow zones

noCO_2

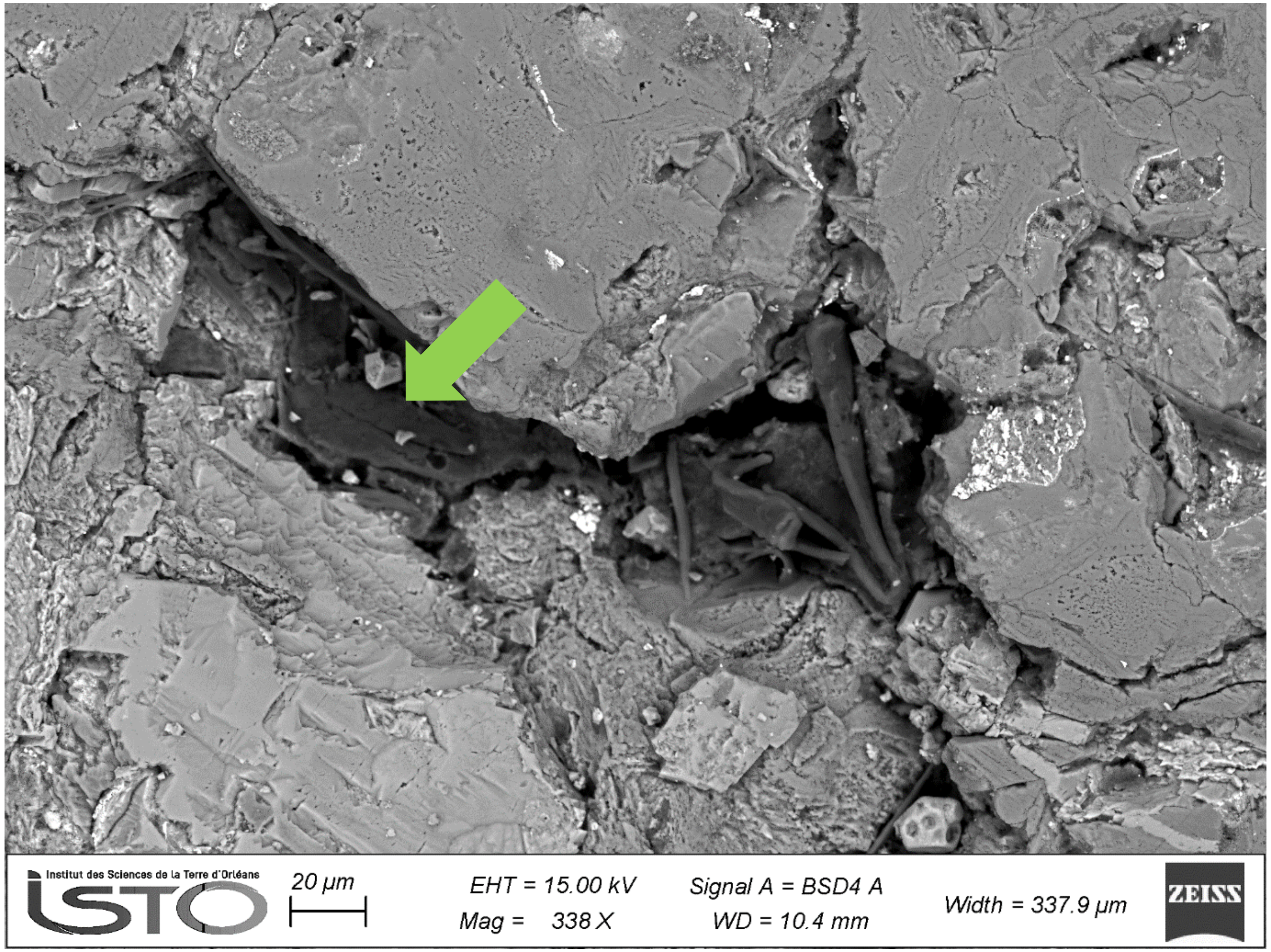
Similar replacement pattern but chrysotile instead of lizardite

Hydrogen production



Osselin et al. *Nature Geoscience* **2022**

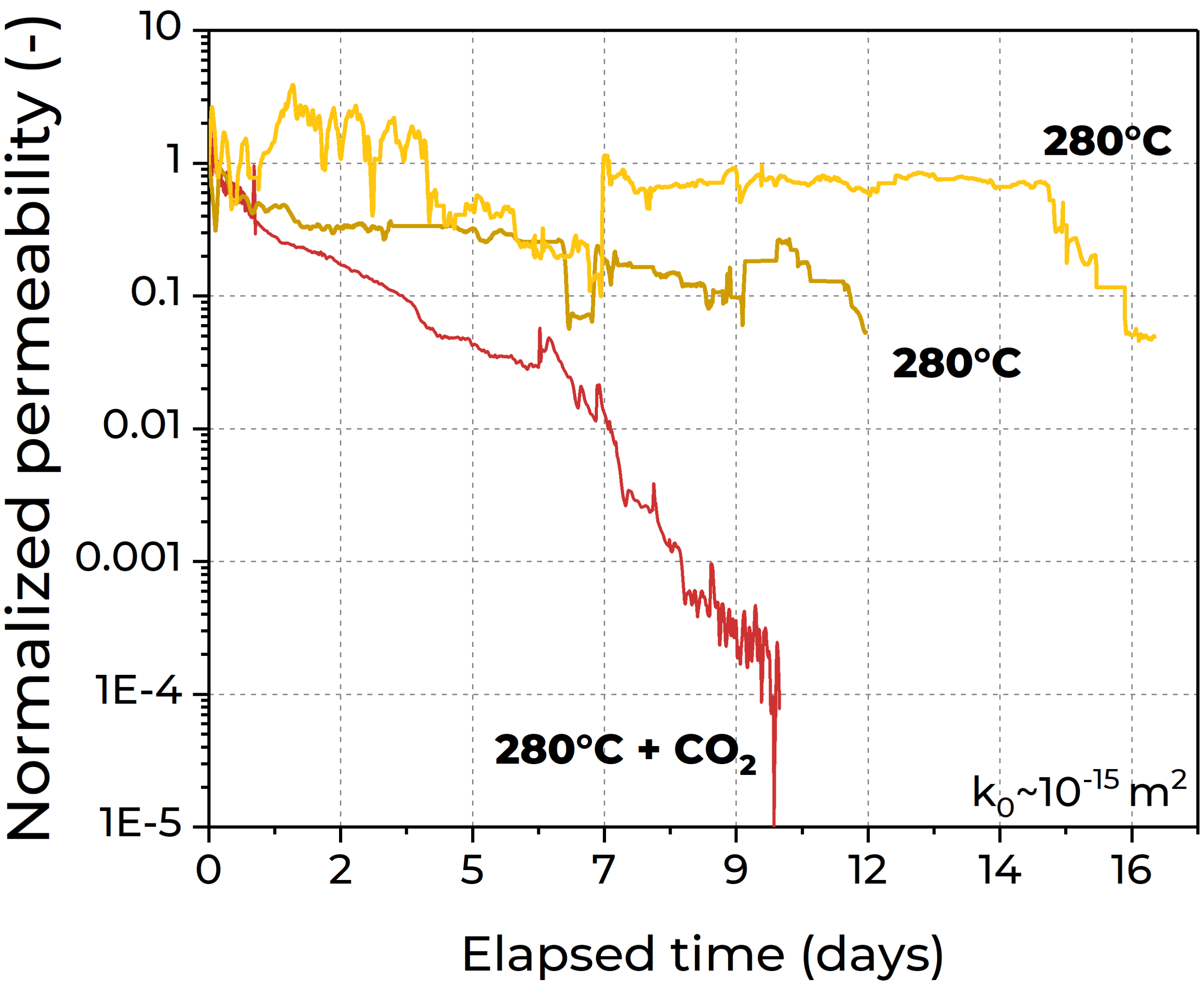
CO_2/H_2 interaction



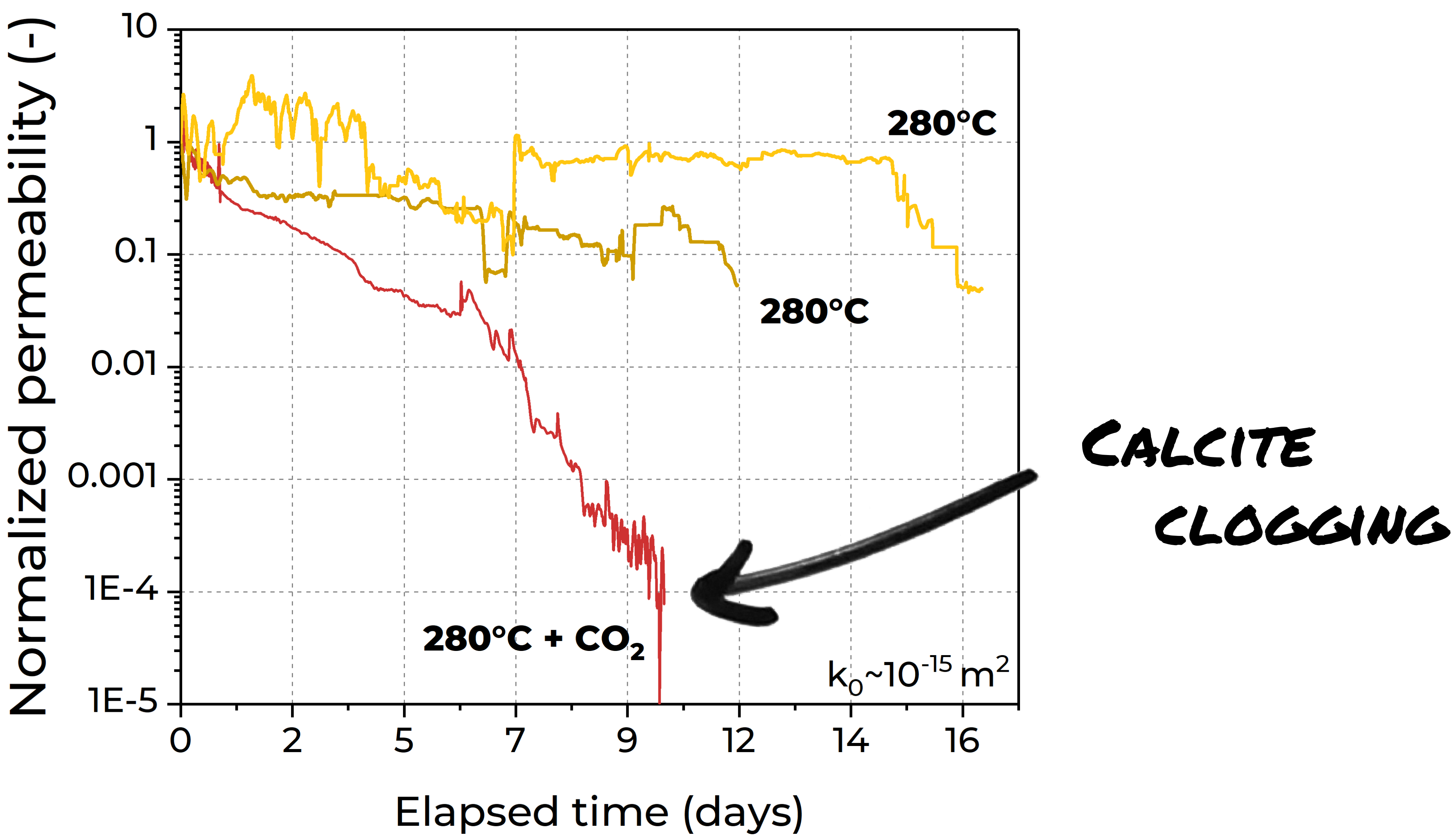
Carbonaceous matter likely generated by CO_2 reduction with H_2

$nCO_2 + xH_2 \rightarrow C_nH_m + H_2O$

Permeability evolution



Hydrochemical Coupling – Permeability evolution



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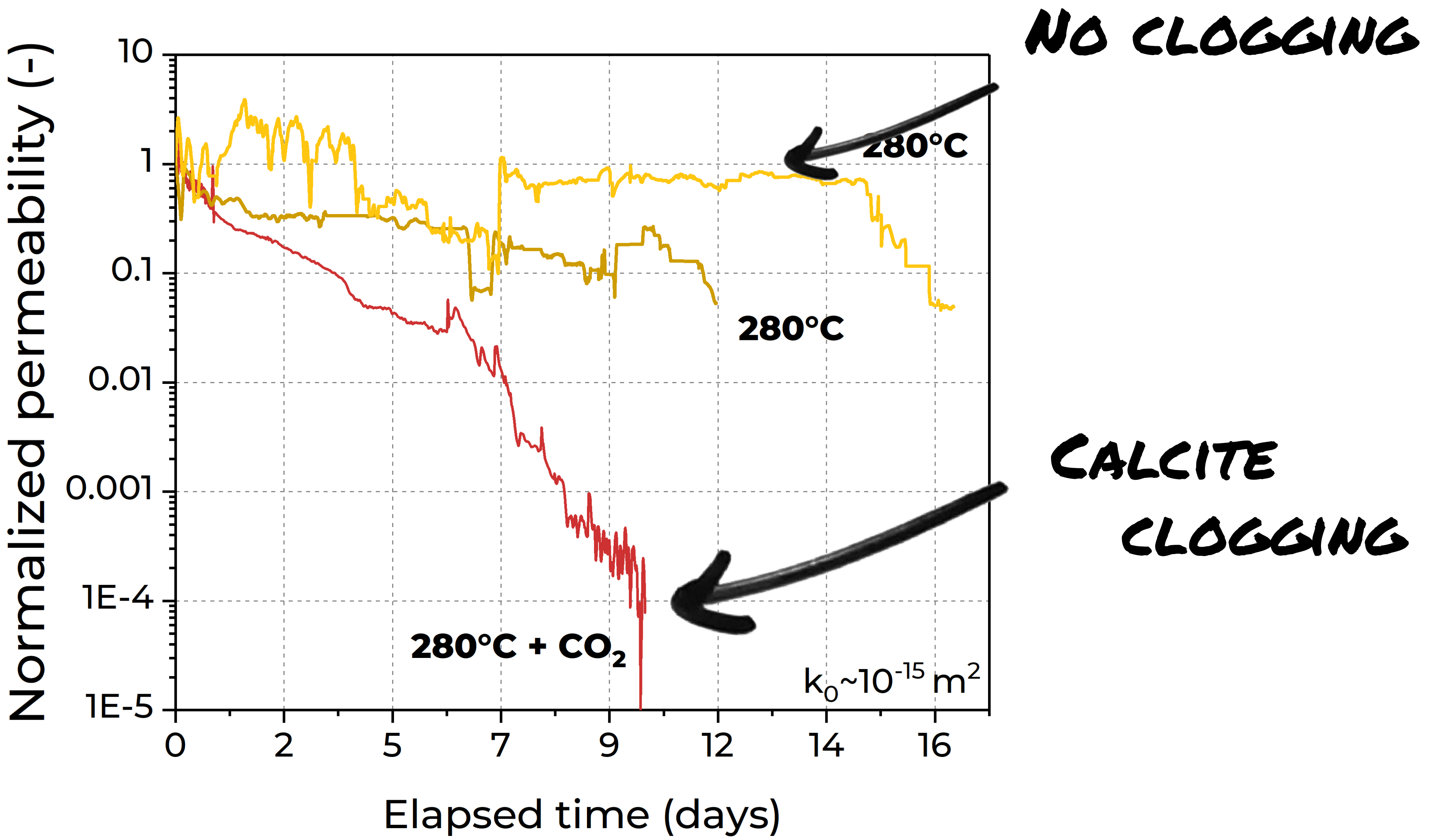
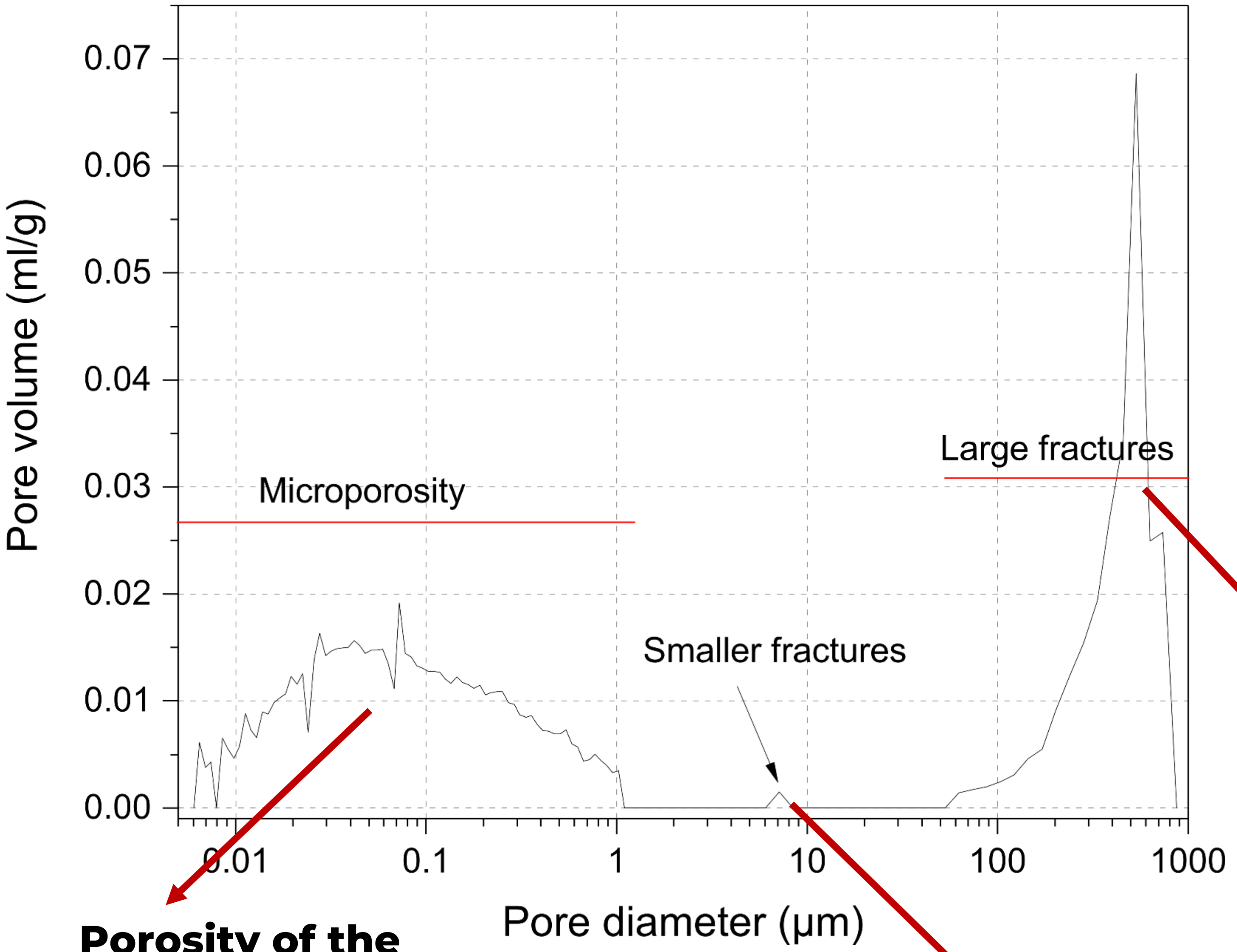


Hydrochemical Coupling



Main percolation paths

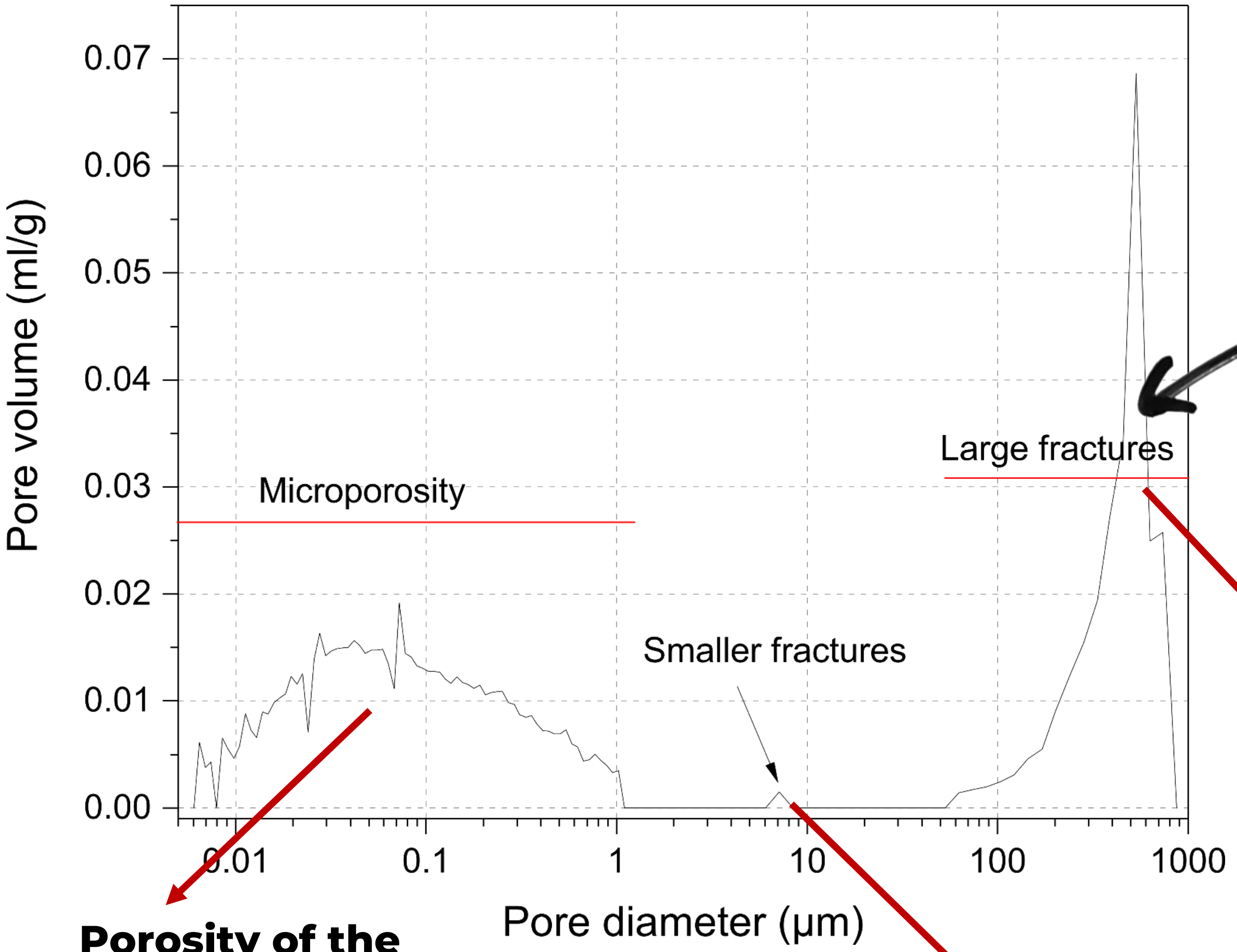
Focus most of the flow

Porosity of the serpentine matrix

Almost no flow

Secondary percolation paths

Hydrochemical Coupling



NEED TO PRECIPITATE HERE FOR ACTUAL PERMEABILITY DECREASE

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Porosity of the serpentine matrix

Almost no flow

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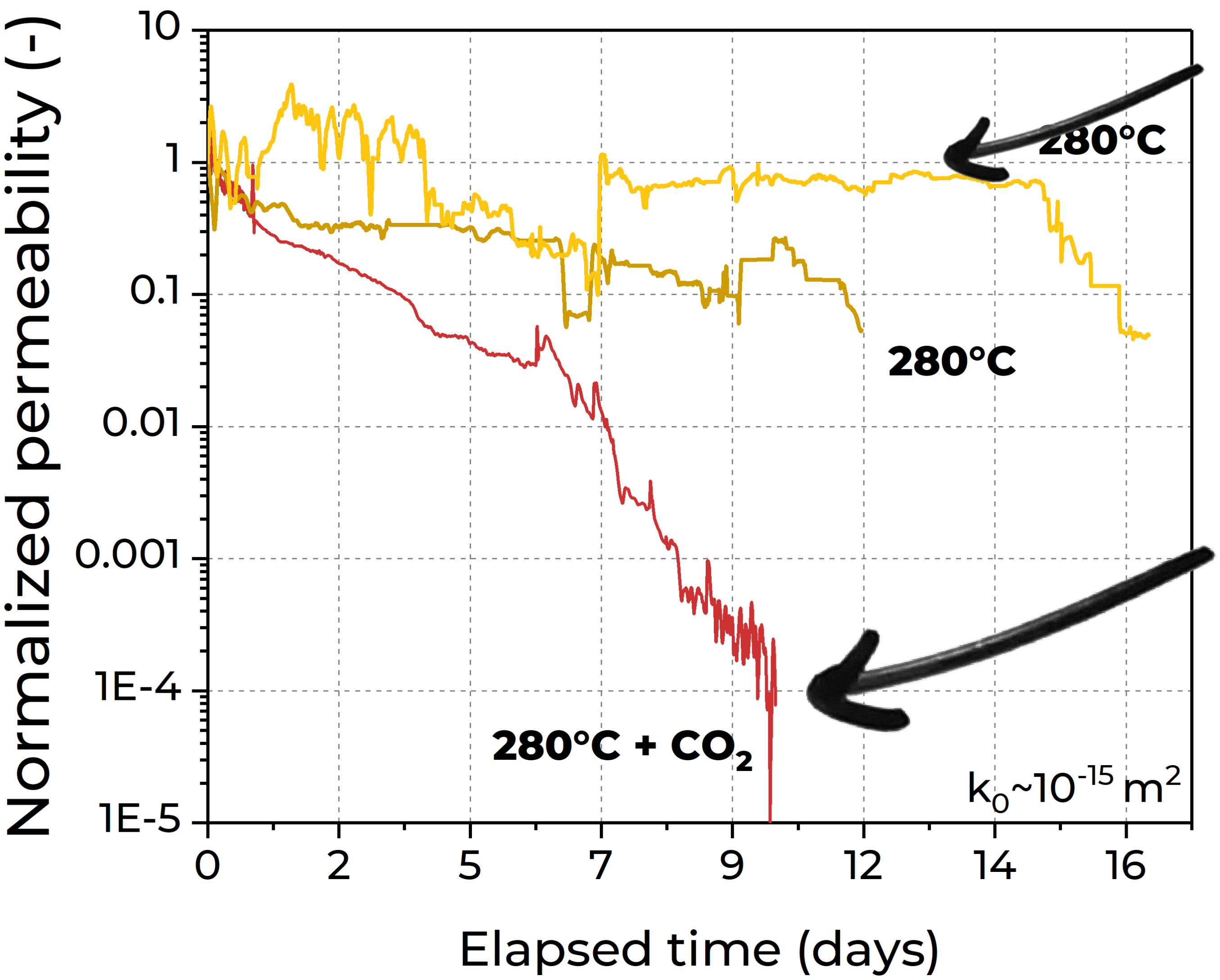
Hydrochemical Coupling – Permeability evolution

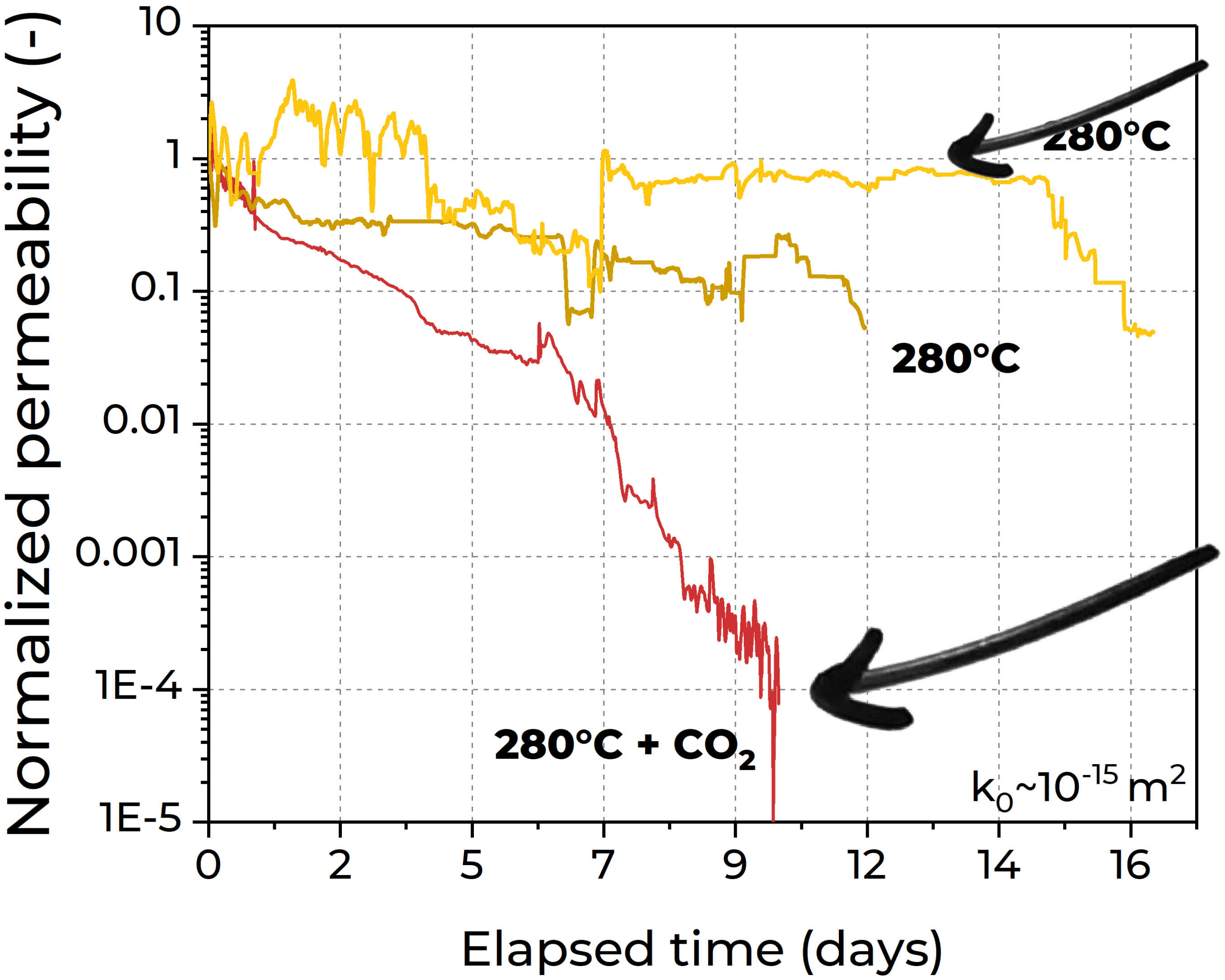


No clogging

Calcite clogging

Calcite is the only mineral precipitating fast enough to clog the main percolation paths

Hydrochemical Coupling – Permeability evolution



No clogging

No mineral is fast enough to precipitate in the main percolation paths

Calcite clogging

Calcite is the only mineral precipitating fast enough to clog the main percolation paths

Scientific Conclusion

- **Importance of THMC coupling in Earth Science processes.**
  - Complicated chemistry
  - Local equilibria
  - Variable flow rates
  - Importance of pressure and mechanics

- **Despite a large molar volume variation, silicates are not responsible for permeability drop.**
  - It’s not the variation of molar volume, it’s the location of the precipitation that matters.

- **Despite clogging, reasonable carbonation of 5.6% of total injected CO_2 at 280° as well as a 3% to 8% H_2 yield in the CO_2-free case.**

Perspectives

- **Potential to be a game-changer for the energy transition**
  - Market of $1000B.

- **The current state of research shows it is possible, but :**
  - What are the best P, T, Q, x conditions of injection?
  - How does the permeability/porosity evolve during the process?
  - How does the surface area evolve – passivation?
  - What is the influence of microbiology on the yield?

LOTS OF SCIENCE TO DO, COLLABORATIONS ARE VERY MUCH WELCOMED!