

Utility of Peridotite Host Rocks for Sequestering Atmospheric Carbon Dioxide

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Abstract

Weathering is a natural geological process whereby atmospheric CO₂ dissolved in rainwater attacks rocks, partly dissolving them. The CO₂ is converted into alkalinity or carbonate minerals that securely store carbon on timescales of >10,000 years. Modelling studies show that if weathering rates can be increased (by selecting the most reactive rocks, increasing reactive surface area), up to an additional 2 Gt CO₂ yr⁻¹ could be removed from the atmosphere, ~40% of the amount required by 2100 to meet the Paris Agreement target.

The mining industry extracts gigatonnes of rock each year, generating large amounts of freshly exposed, reactive surface area that could be used as a feedstock for enhanced weathering. Ore deposits with the highest CO₂ removal capacity are those mined in high quantities that have an abundance of calcium- and magnesium-bearing silicate minerals [1]. Here, we report the results of an investigation into the reactivity of serpentinised peridotite samples from the Sakatti Cu-Ni-PGE deposit (Finland). The deposit consists of both disseminated and massive sulphides hosted within a large olivine-cumulate body [2]. The material consists primarily of serpentine [Mg₃Si₂O₅(OH)₄] and olivine [Mg₂SiO₄] minerals that have a high potential for CO₂ removal via enhanced weathering.

We have conducted a series of laboratory experiments whereby crushed peridotite samples were reacted with CO₂-enriched solutions at 25 °C and 50 °C, and 1 bar CO₂ (100% CO₂). Surface area normalised dissolution rates were determined for various grain sizes, temperatures, mineral compositions (degree of serpentinization) and solution chemistry (with/without a chelating agent).

(Bullock et al., 2021; Brownscombe et al., 2015; Calvin et al., 2023; Beerling et al., 2020; Kelemen et al., 2020; Renforth, 2019)

References

- Global Carbon Dioxide Removal Potential of Waste Materials From Metal and Diamond Mining. (2021). *Frontiers in Climate*, 3. <https://doi.org/10.3389/fclim.2021.694175>
- The Sakatti Cu-Ni-PGE Sulfide Deposit in Northern Finland. (2015). In *Mineral Deposits of Finland* (pp. 211–252). Elsevier. <https://doi.org/10.1016/b978-0-12-410438-9.00009-1>
- IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.. (2023). In P. Arias, M. Bustamante, I. Elgizouli, G. Flato, M. Howden, C. Méndez-Vallejo, J. J. Pereira, R. Pichs-Madruga, S. K. Rose, Y. Saheb, R. Sánchez Rodríguez, D. Ürges-Vorsatz, C. Xiao, N. Yassaa, J. Romero, J. Kim, E. F. Haïtes, Y. Jung, R. Stavins, ... Y. Park (Eds.), *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate*

Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.. Intergovernmental Panel on Climate Change (IPCC). <https://doi.org/10.59327/ipcc/ar6-9789291691647.001>

Potential for large-scale CO₂ removal via enhanced rock weathering with croplands. (2020). *Nature*, 583(7815). <https://doi.org/10.1038/s41586-020-2448-9>

Engineered carbon mineralization in ultramafic rocks for CO₂ removal from air: Review and new insights. (2020). *Chemical Geology*, 550. <https://doi.org/10.1016/j.chemgeo.2020.119628>

The negative emission potential of alkaline materials. (2019). *Nature Communications*, 10(1). <https://doi.org/10.1038/s41467-019-09475-5>

1 Introduction

- Global climate change demands immediate action, with anthropogenic activities pushing CO₂ concentrations beyond 410ppm, risking a **temperature increase of 3.7–4.8 °C by 2100** (IPCC, 2023).
- The **mining industry**, known for it's substantial environmental impact, annually produces **gigatonnes of waste rocks rich in reactive minerals** (Bullock et al., 2021).
- Enhanced weathering**, leveraging waste from the mining sector, presents a scalable solution to **remove up to 2 Gt CO₂/yr**, supplementing natural weathering rates (Beerling et al., 2020).

2 The Rocks

This study investigates the reactivity of **serpentinised peridotite** samples from the Sakatti deposit in Finland, and a confidential mine location in South Africa, aiming to **identify materials with high CO₂ removal potential**.



Key XRF Oxides (Wt. %)	SiO ₂	Fe ₂ O ₃	MgO	CaO	LOI	Total	Enhanced Weathering Potential [Epot*] (Kg CO ₂ per tonne rock)
PRD	36.15	8.71	40.37	1.54	9.8	98.06	907.5
DUN	37.92	9.68	42.9	0.66	5.5	98.19	950.55
CONF.A	34.07	9.41	40.45	0.05	14.9	99.44	895.28

$$E_{pot} = \frac{M_{CO_2}}{100} \cdot \left(\alpha \frac{CaO}{M_{CaO}} + \beta \frac{MgO}{M_{MgO}} + \epsilon \frac{Na_2O}{M_{Na_2O}} + \theta \frac{K_2O}{M_{K_2O}} + \rho \frac{MnO}{M_{MnO}} + \gamma \frac{SO_3}{M_{SO_3}} + \delta \frac{P_2O_5}{M_{P_2O_5}} \right) \cdot 10^3 \cdot \eta$$

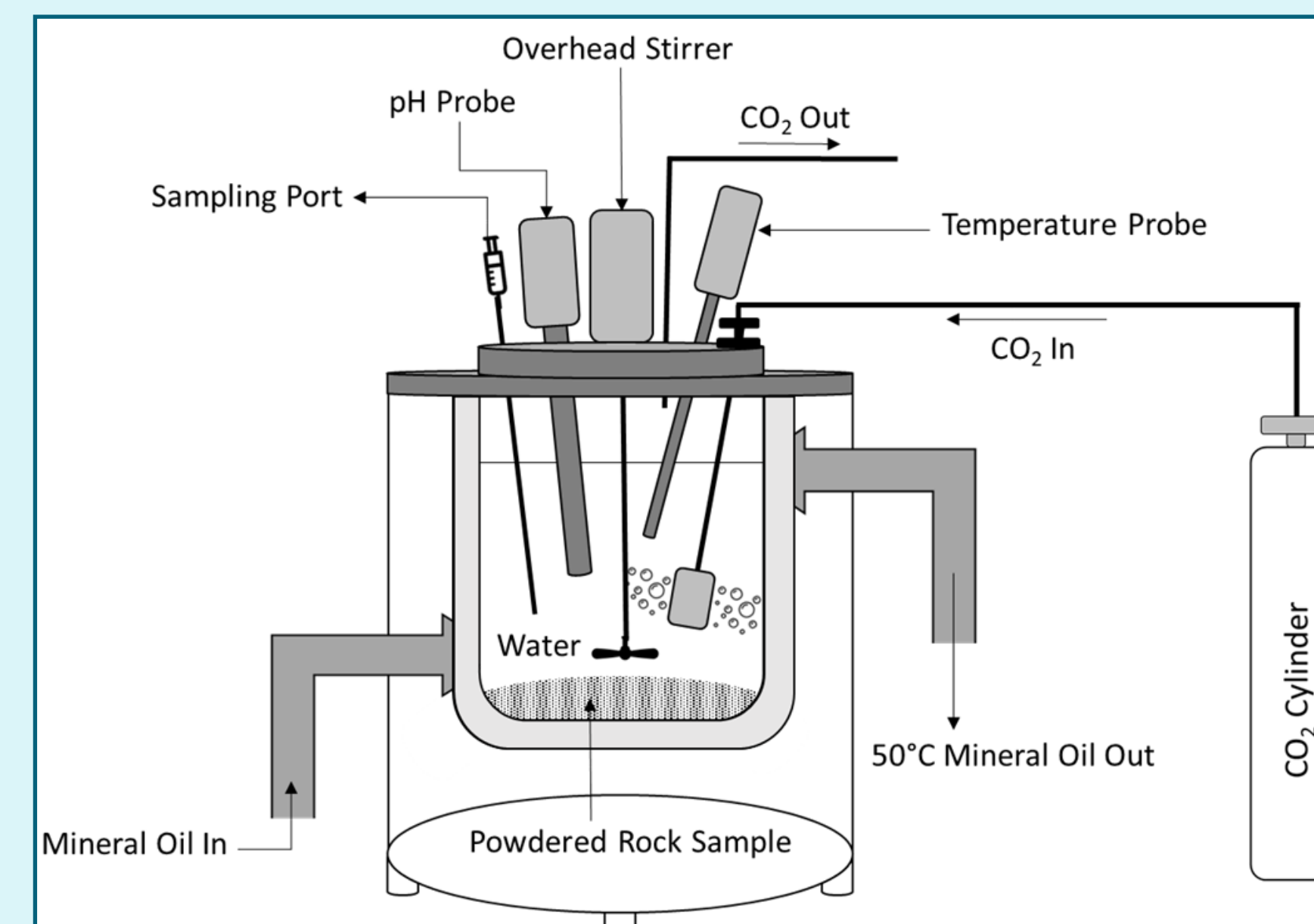
(Renforth, 2019)

Key Minerals (Wt. %)	Serpentine	Forsterite	Brucite	Chlorite	Magnetite	Stichtite	Calcite	Diopside	Talc	Hornblende
PRD	39.7	36.8	-	8.1	-	-	0.6	2.7	11.8	-
DUN	13.5	77.3	-	4.9	-	-	-	-	1.6	1.4
CONF.A	87.8	-	4.9	-	4.6	2.8	-	-	-	-

3 Dissolution Method

- All three lithologies (PRD, DUN, CONF.A) were characterised using thin section petrography, XRD, XRF and SEM-EDS.
- Core samples were crushed and sieved into **two size fractions** for reaction with CO₂: **180–250 μm** (PRD_200) and **750–1000 μm** (PRD_1000). Particle size distributions and surface areas (BET and Geometric) were determined for these size fractions.
- To assess CO₂ reactivity, **900ml Mili-Q water was continuously saturated with CO₂ (100% CO₂)** and **20g of powdered rock sample** was added. Fluid samples were regularly collected for ICP-OES and alkalinity analysis.

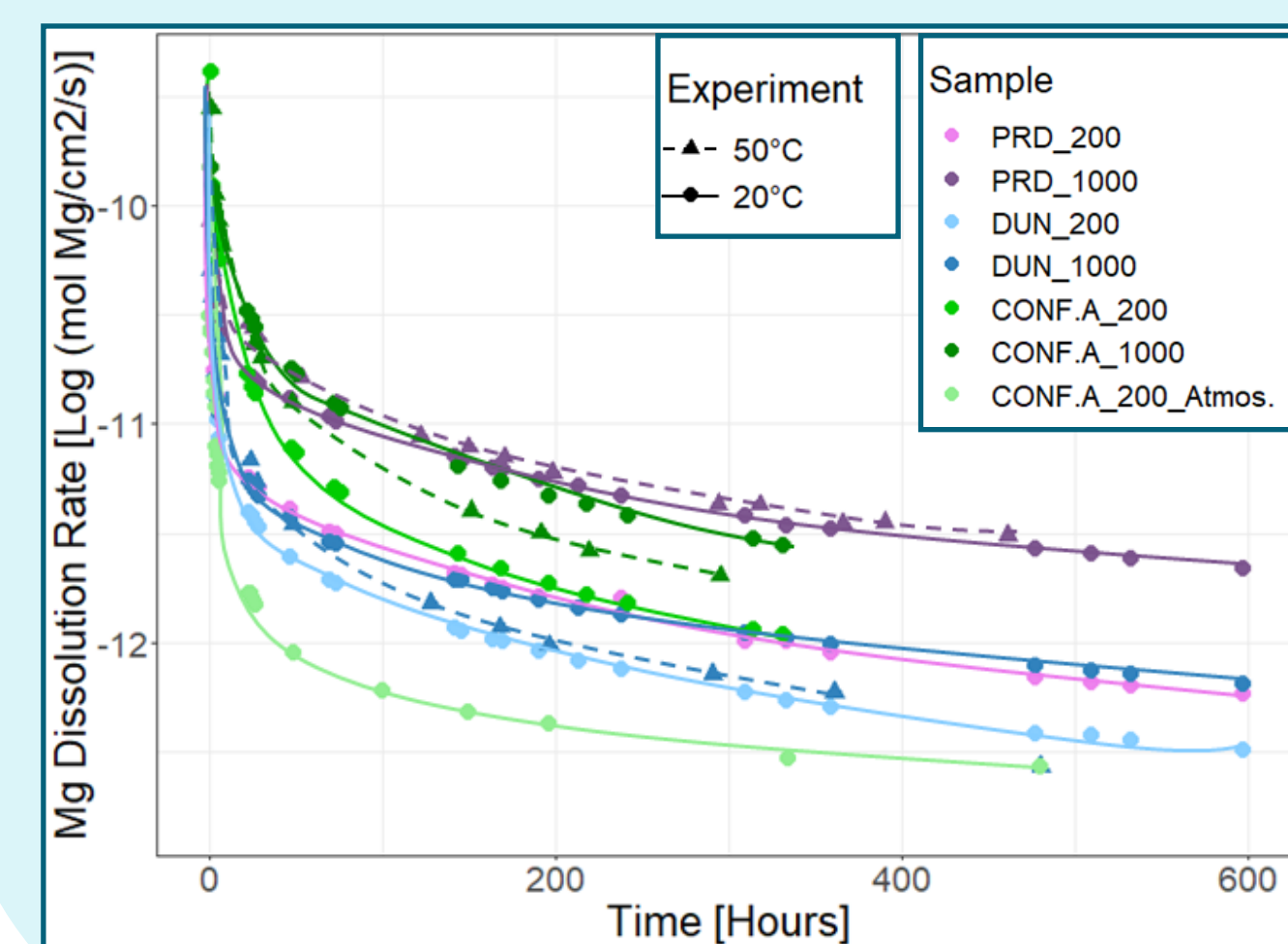
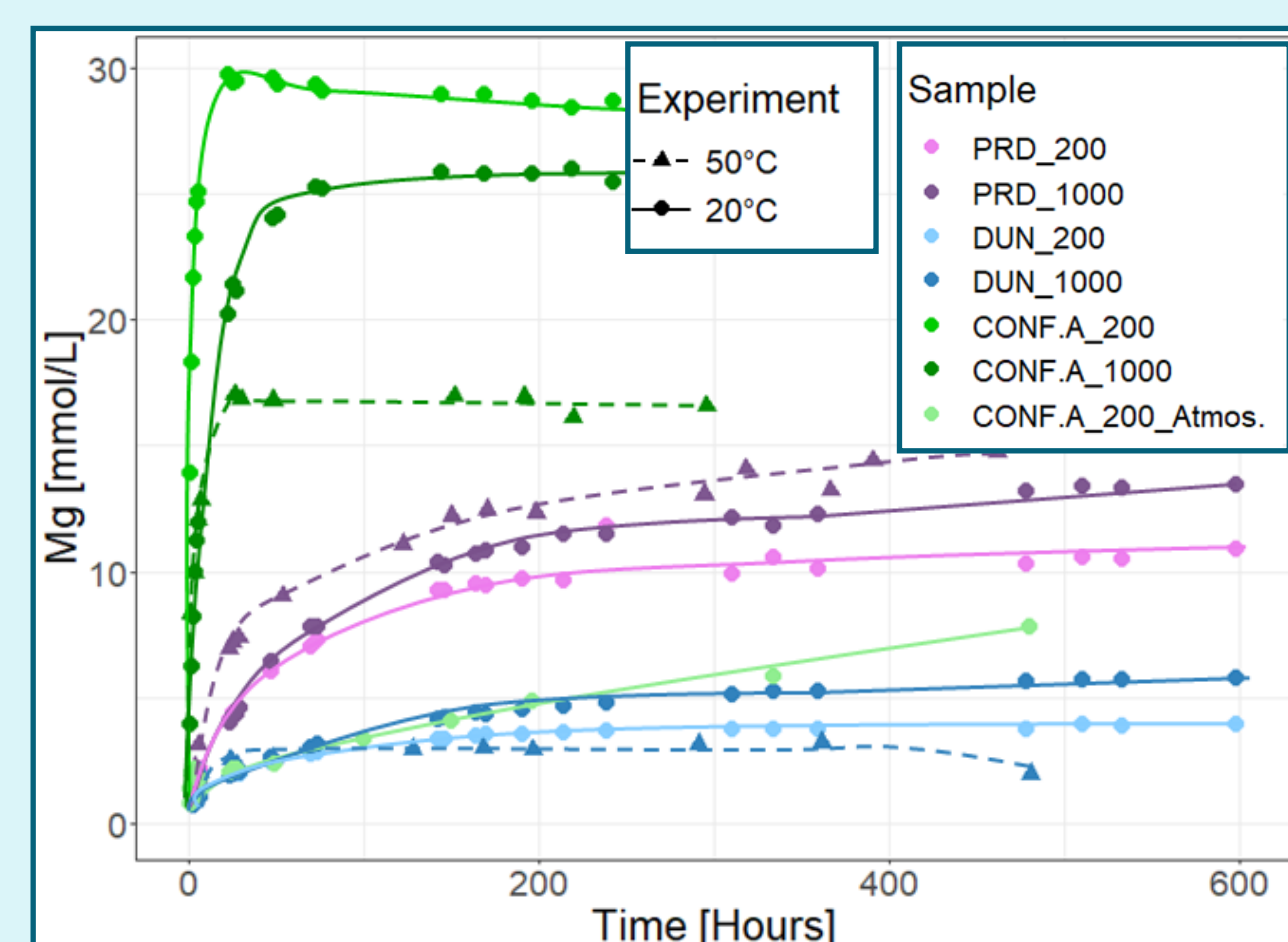
- Experiments were conducted at **room temperature (20°C)** and **50°C** (PRD_1000_50).



Peridotite host rocks are efficient at sequestering CO₂, especially if they contain brucite, but we need to make it faster!

4 Dissolution Results

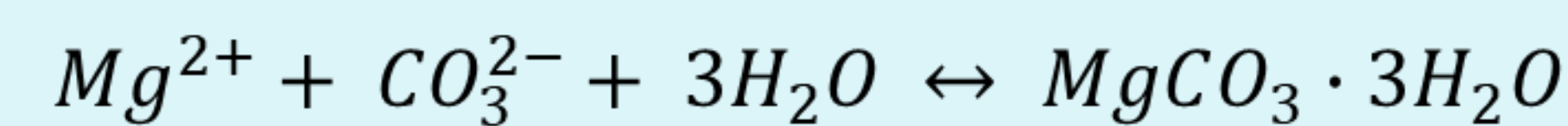
- Samples **do not always** react faster at higher temperatures.
- Smaller grain sizes **do not always** react faster.



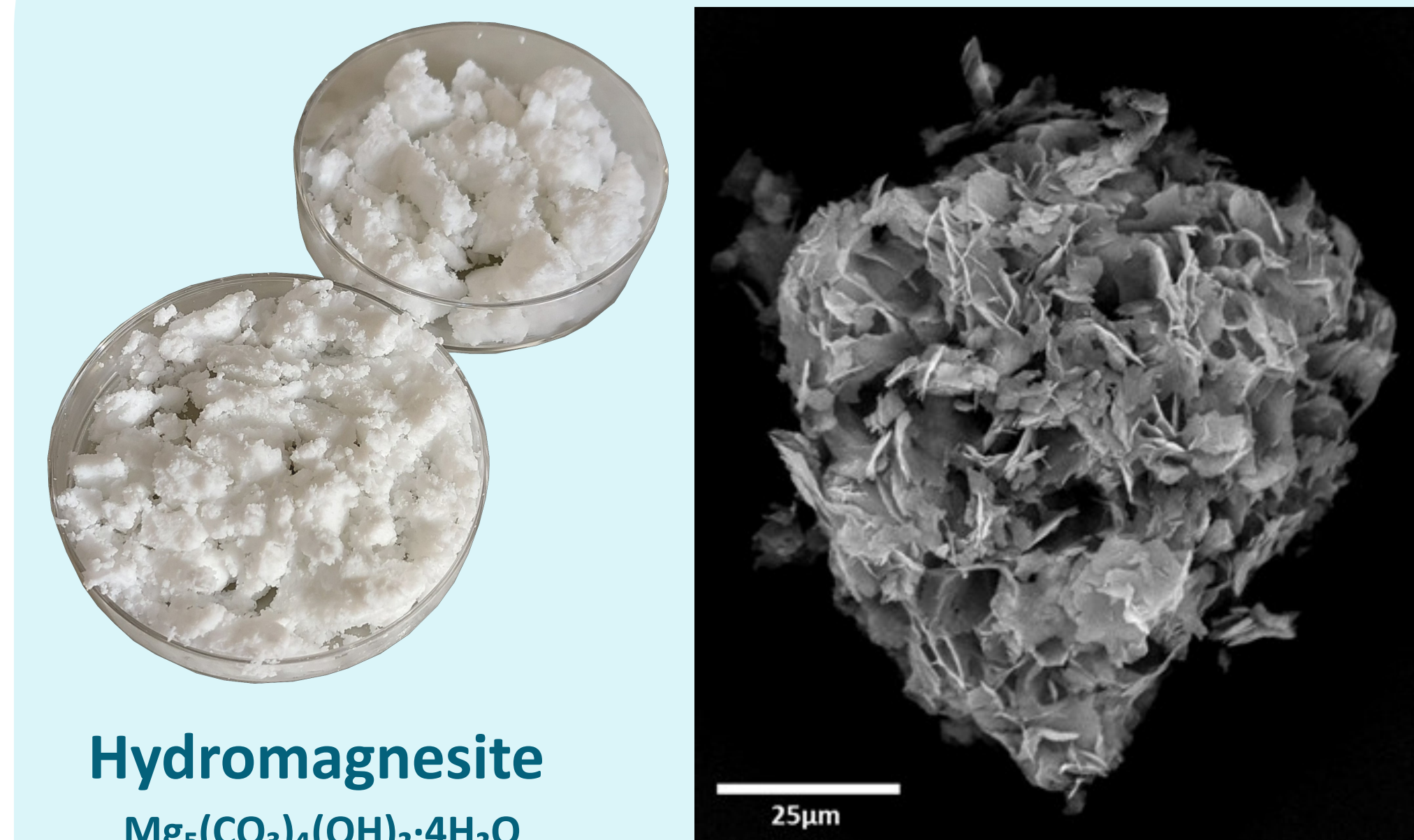
- Mg dissolution rates are normalised to Geometric Surface Area.
- Surface area normalisation is key!**

5 Precipitation Method

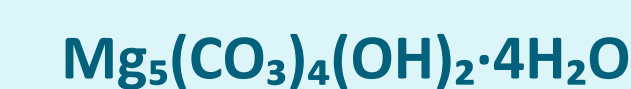
- Final fluids** from the dissolution experiments were collected and **filtered** to remove any remaining rock powder.
- The filtered fluids were **heated** to just below boiling point and **agitated** using a magnetic stirring hot plate.
- Evaporation** of the fluid was continued **until approx. 50ml** of fluid remained.
- Any **precipitation** that formed during this process was filtered out of solution, dried, weighed and analysed by XRD to determine mineralogy.
- All fluids were sampled before and after precipitation for ICP-OES, alkalinity and DIC analyses.



6 Precipitation Results

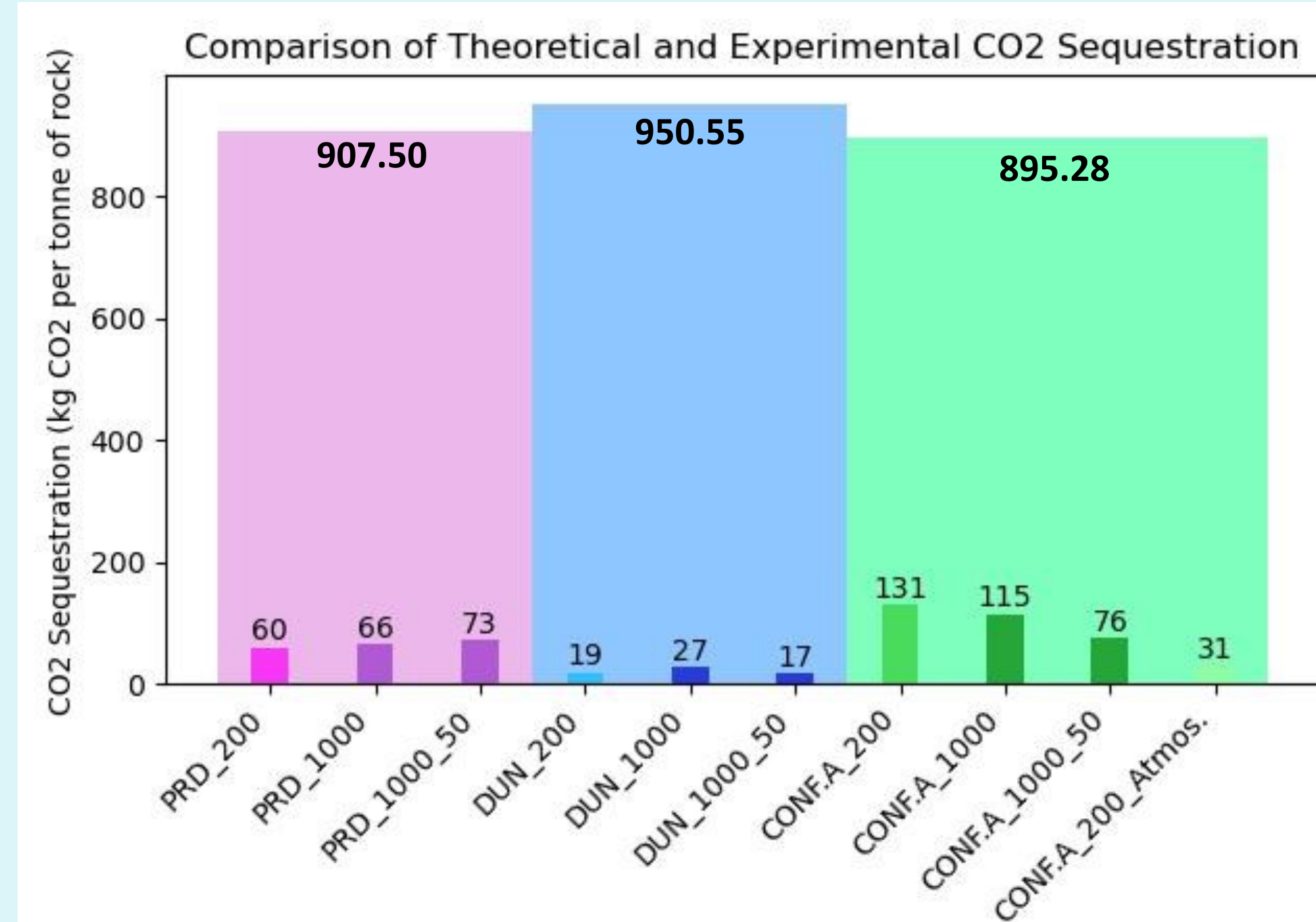


Hydromagnesite



	Pre-Precipitation		Mass of Precipitate (g)	Post-Precipitation	
	Alkalinity (mmol/L)	Mg (mmol/L)		Alkalinity (mmol/L)	Mg (mmol/L)
PRD	35.6	12.38	0.65	2.5	1.38
DUN	38.6	3.82	0.21	1.9	0.46
CONF.A	121.3	18.73	1.04	3.2	0.19

7 CO₂ Sequestration



$$CO_2 = 2 (Mg_F + Ca_F) * Mm_{CO_2}$$

(Kelemen et al., 2020)

- The current experimental values are **significantly lower** than the theoretical enhanced weathering potential (Epot).
- To come close to realising this potential, **substantial improvements** in the experimental processes are **necessary to enhance efficiency**.