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NATURAL ENVIRONMENT RESEARCH COUNCIL

Gateway to the Earth

CO_2-water-rock reactivity at hydrothermal temperatures: The 'BigRig2' experiment

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Clean energy challenges

1) EU needs clean energy & to reduce import dependency → enhanced (or engineered) geothermal systems (EGS).

2) EU requires reductions in CO_2 emissions to the atmosphere → storage underground.

C Rochelle

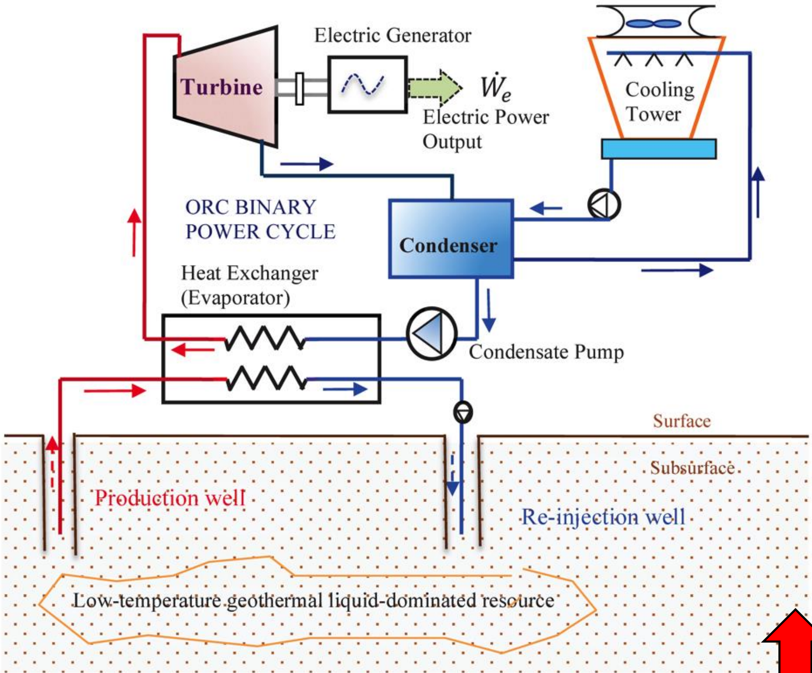
CO_2-EGS as a combined solution ?

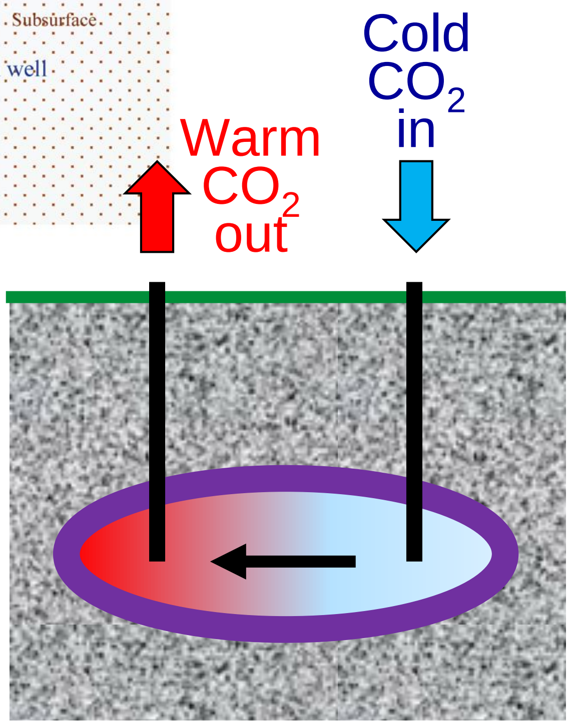
1) Inject CO_2 dissolved in water as part of an otherwise conventional EGS. Geochemical reactions ‘trap’ the CO_2 as secondary carbonate phases.
2) Inject free-phase CO_2 as the working fluid of a new type of CO_2-based EGS. Thermodynamic and physical properties of CO_2 enhance heat recovery. Geochemical reactions help isolate the CO_2 from the surrounding water-filled rock through the precipitation of secondary carbonate phases.

Gunter-type reaction:

$$\underset{\text{Anorthite (Ca-fsp)}}{CaAl_2Si_2O_8} + CO_{2(aq)} + 2\,H_2O \Rightarrow \underset{\text{calcite}}{CaCO_3} + \underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_4}$$

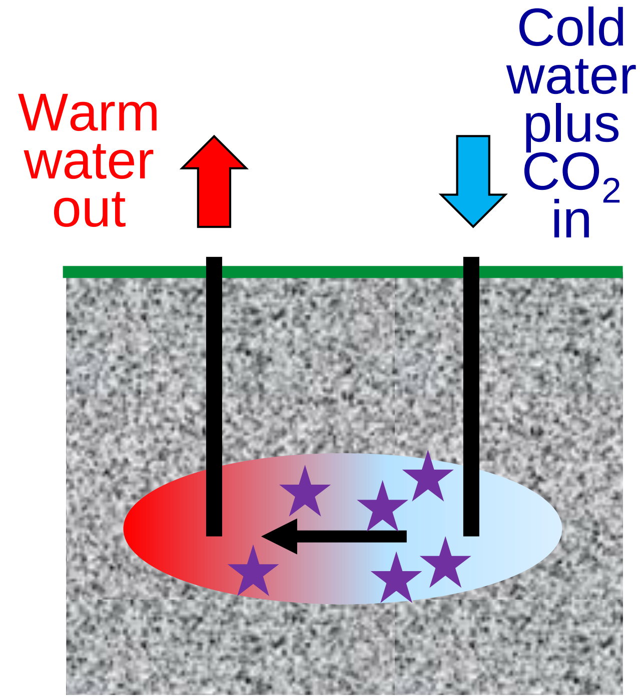
Concepts for CO_2 reaction





CO_2 working fluid: Geochemical reactions lead to blocking of porosity at the boundary of CO_2-filled and water-filled rock => low permeability seal/shell isolating CO_2 EGS fluid

(e.g. Pruess 2006)

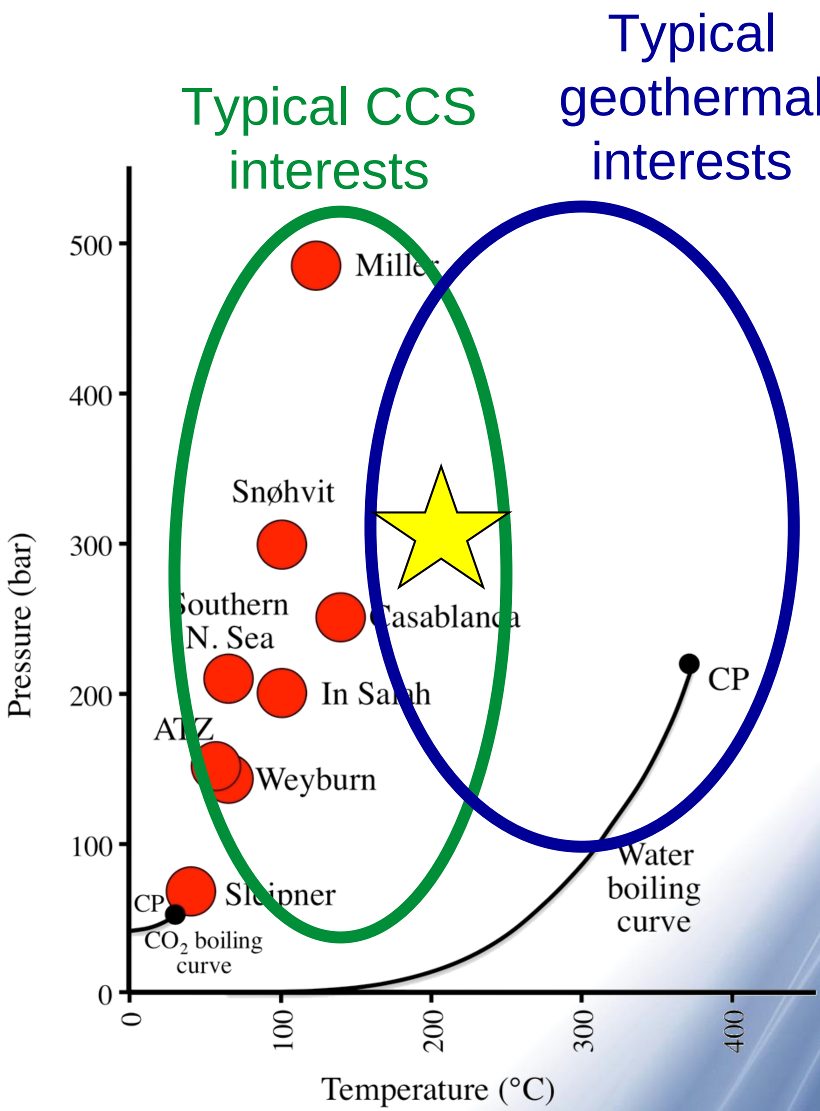


CO_2-water-rock reactions precipitate carbonates within the rock

(e.g. CO_2-DISSOLVED project, Kervévan et al. 2017)

Learning from the CCS community

- CCS researchers have used lab experiments to understand the evolution of rocks with stored CO_2 (and impurities).
- They have increased temperatures to speed up rates of reactions.
- These experimental conditions have relevance to CO_2-enhanced geothermal systems.
- Can we (re-)use that data?

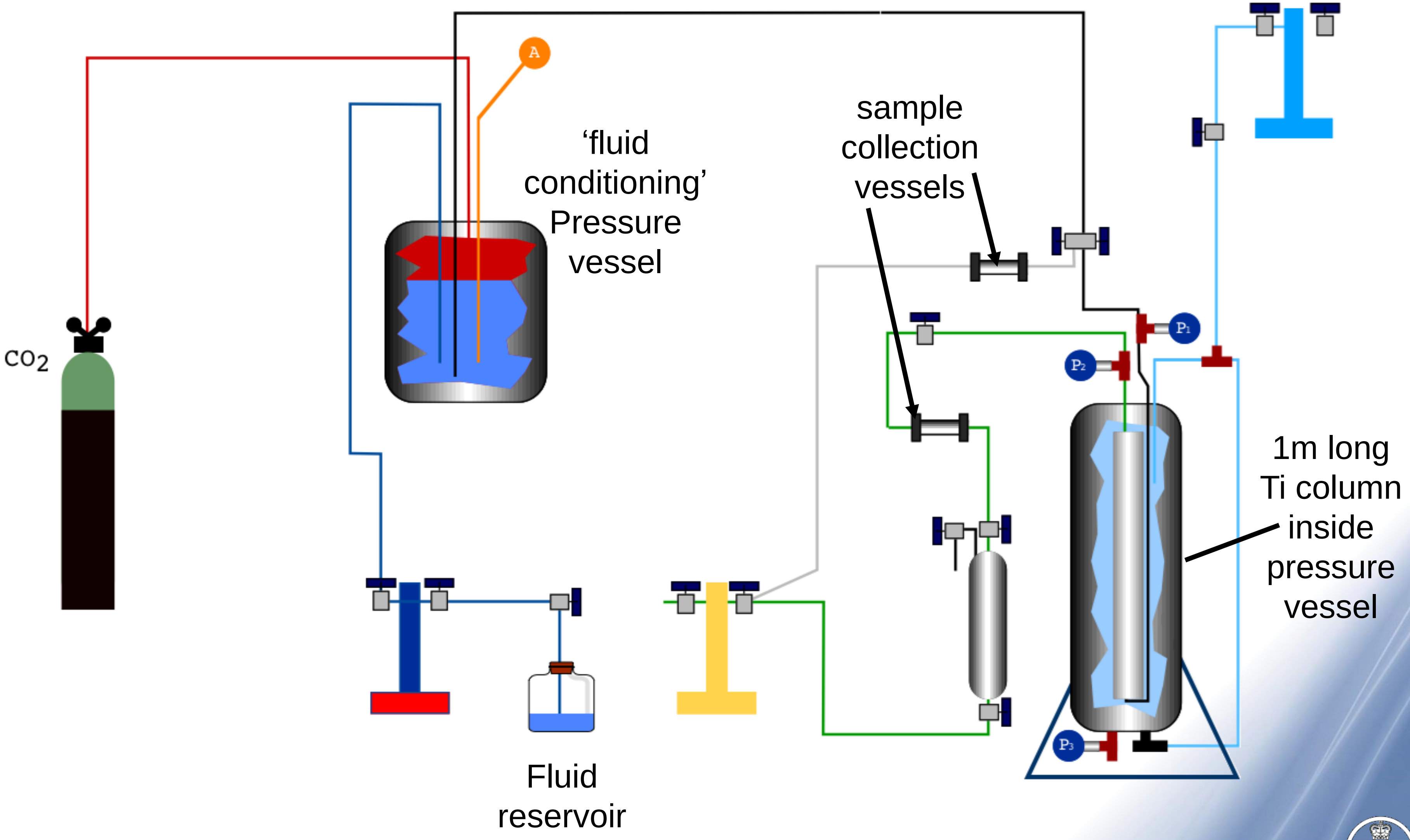


The 'BigRig2' experiment

- Conceived as a part of CO_2GeoNet to provide a well-controlled lab dataset with which to compare predictions from geochemical models.
- Main input groups were BGS (experiment and analysis) and BRGM (modelling).
- Reacted a precisely-known mixture of mineral phases with CO_2-rich water in a 1m long flow experiment at 130°C and 300 bar for 3.5 months. Regular sampling and analysis of output fluids, and full mineralogical characterisation at the end of the test.
- The experimental dataset, together with pre- and post-test modelling are available.


Caution

Simplified experiment layout



Experimental conditions

- Temperature 130°C; pressure 300 bar; CO_2-saturated water
- Column 1 m long, 3.5 cm diameter
- Flow rate 5 ml / hr
- Total duration of experiment 105 days
- Fluid and solids based on ‘simplified’ Utsira Sand composition (i.e. Sleipner site), but this could also represent generic continental crust composition.

pH determined on depressurised fluids and under *in situ* conditions.

Synthetic formation fluid

pH 7.1 (at 20°C)

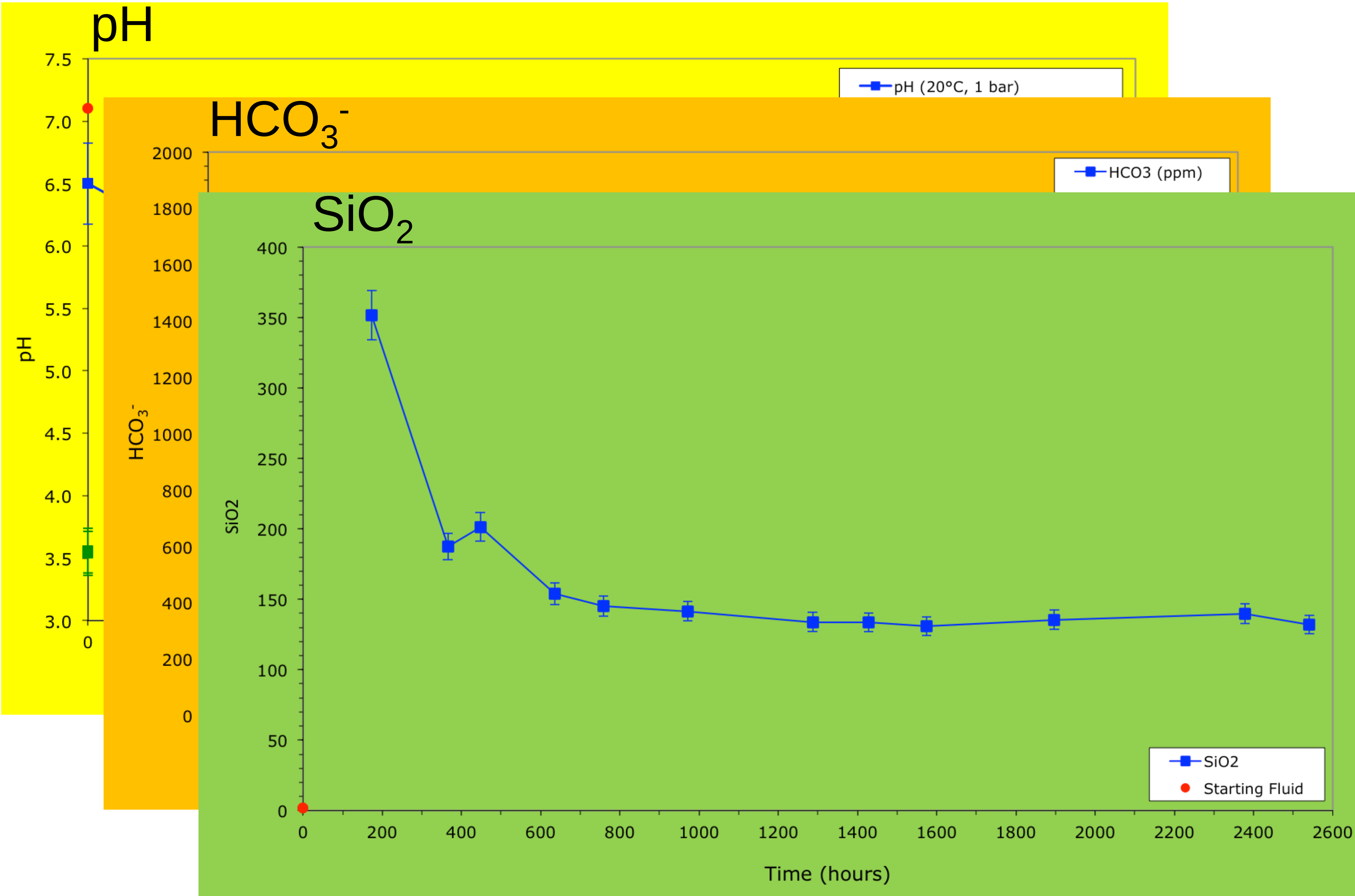
	Concentration ppm	(mol dm^{-3})
Na	11495	(5.00×10^{-1})
K	1.35×10^{-5}	(3.46×10^{-10})
Ca	48.49	(1.21×10^{-3})
Cl	17807	(5.02×10^{-1})
HCO_3	1.91	(1.59×10^{-4})

Mineral composition

(synthetic mixture of sand-sized grains)

Phase	Experiment Weight %
Quartz	70
‘Labradorite’	20
‘Calcite’	5
‘Muscovite’	5
Mixture	100

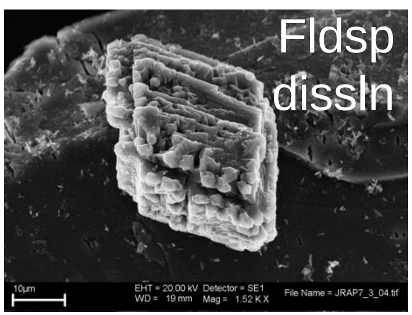
Typical fluid chemical data



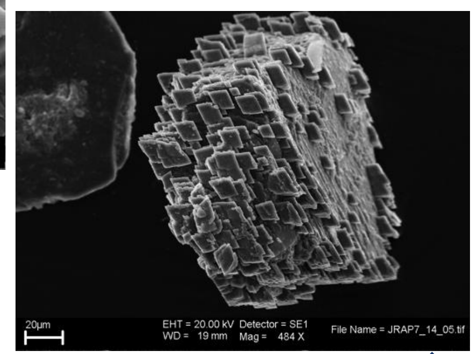
Mineral reactions

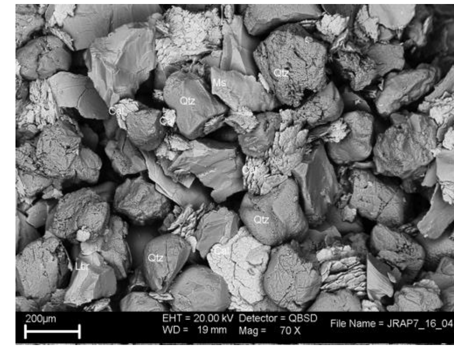
Column sawn into 2.5 cm long sections and analysed.

- Calcite dissolution: first ≈10 cm of the column, reappears ≈ 28 cm
- Labradorite: dissolution throughout the column, but especially at inlet end
- Precipitation of calcite cement from ≈75.5 cm
- Al-rich, clay-like precipitates: first 15 cm of the column
- Fe/Mn carbonate precipitates from ≈ 28 cm

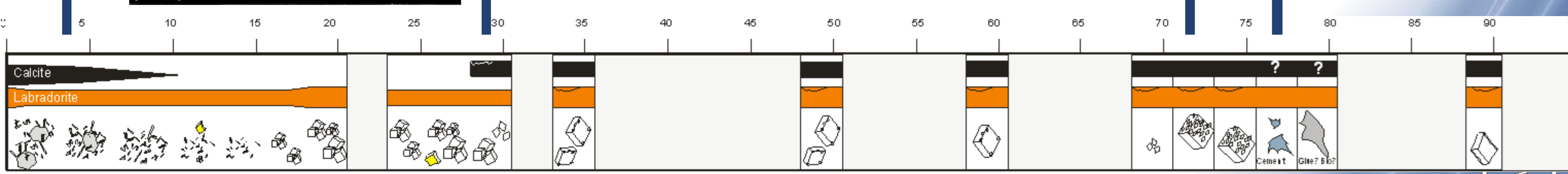


Fe-enriched carbonate overgrowths





Calcite precipitate



FLOW

Modelled conditions

- Temperature 130°C, Pco_2 125 bar and 325 bar (fco_2 of 100 and 300 bar)
- PHREEQC used to perform both 'blind' pre-test modeling, and also post-test modelling refined by the experimental results.

Synthetic formation fluid

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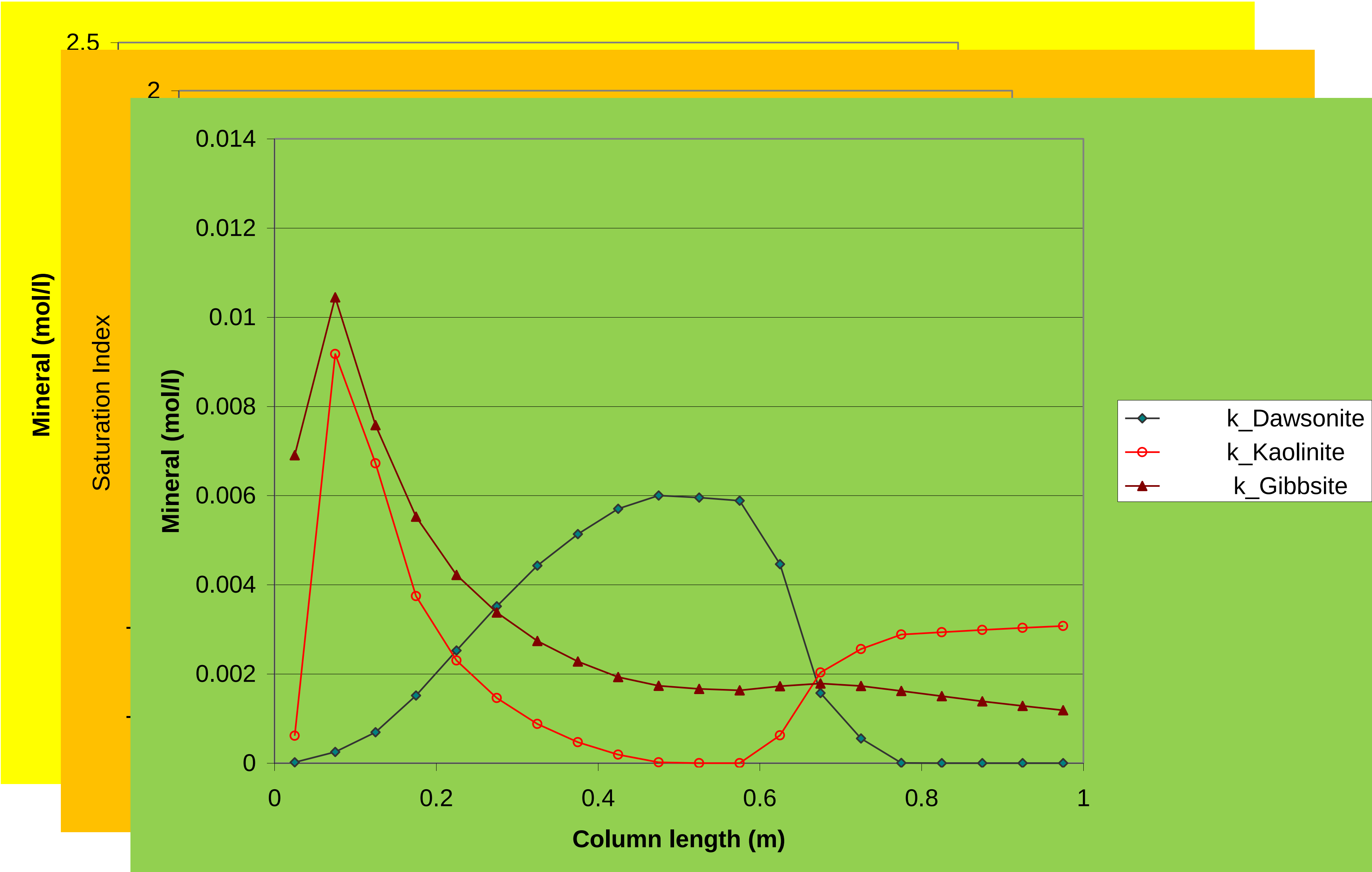
Mineral composition

	Model	Surface area
Phase	mol / kg	m^2 / g
Quartz (70%)	46.5	3.6
Albite (10%)	1.52	18.3
Anorthite (10%)	1.44	"
Calcite (5%)	2.1	3.5
Muscovite (5%)	0.54	601

Geometry	
Column length	100 cm
Column diameter	3.5 cm
Number of cells	20
Hydrodynamics	
Porosity	0.395
Flow rate	5 cm^3 / h
Dispersivity	1 cm
Diffusion coefficient	0

Simulation outputs for 125 days

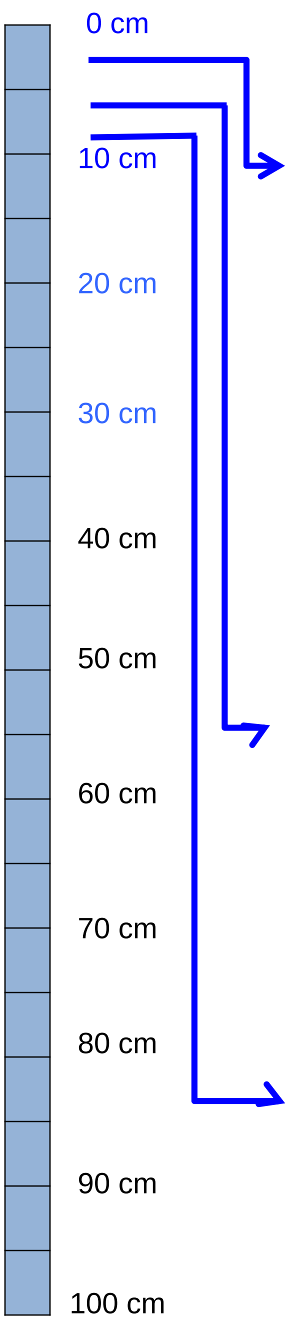


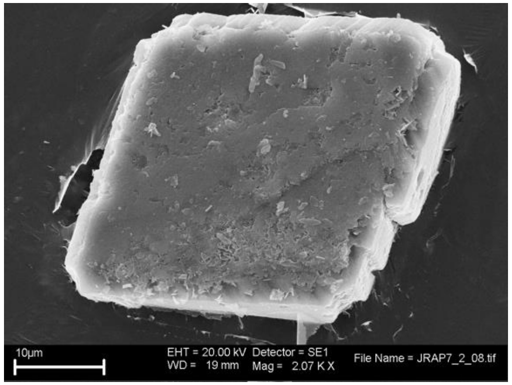
Summary

- There is scope to either use or sequester CO_2 within engineered geothermal systems.
- Critical amongst the resulting geochemical reactions are those that ‘trap’ CO_2 in secondary carbonate minerals, and those that fill porosity / reduce permeability.
- Observational data with which to test predictive models are scarce, but there is scope to translate knowledge from the CCS community to the geothermal community.
- The ‘BigRig2’ experiment is one such example, where a pre-existing dataset exists, together with modelling.
- The experiment captures a system where acidic, CO_2-rich fluid initially dissolves minerals (calcite and feldspar), but continued fluid-rock reactions moderate pH, leading to carbonate saturation and its precipitation.

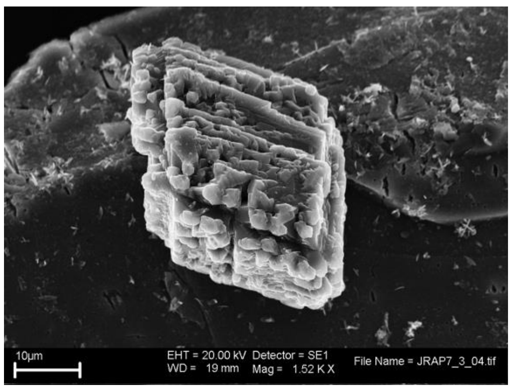
Extra information

Calcite Dissolution



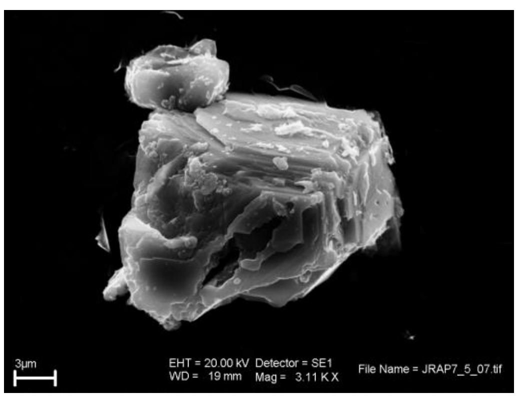


0-3cm



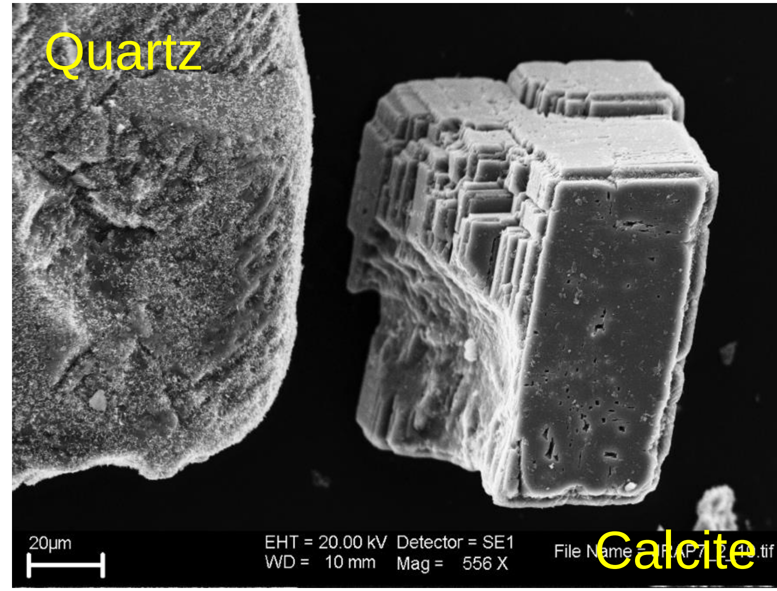
5.5-8cm

Extensive dissolution



8-10.5cm

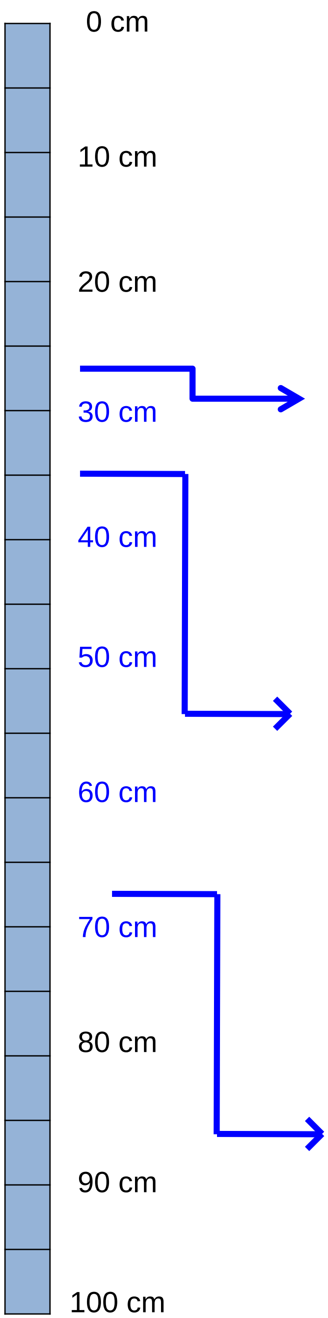
Etched

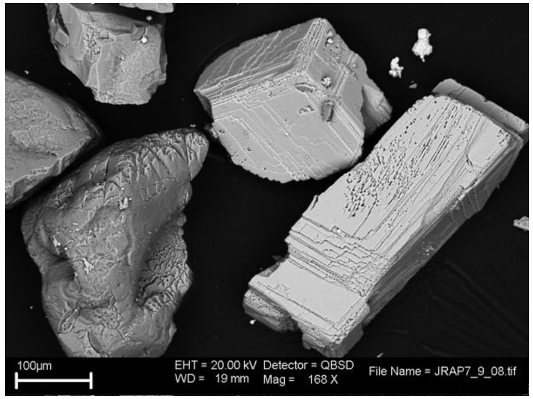


Dissolution on crystal faces + edges

10.5-28cm – no calcite remaining

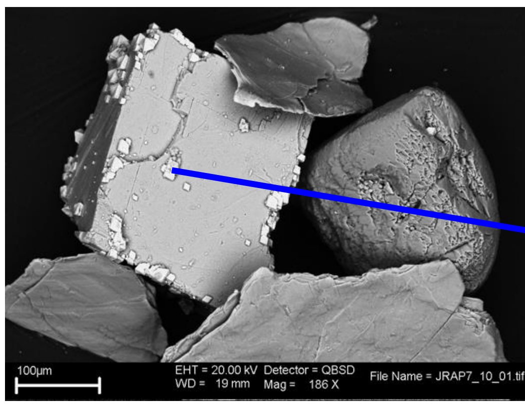
Calcite Reappearance





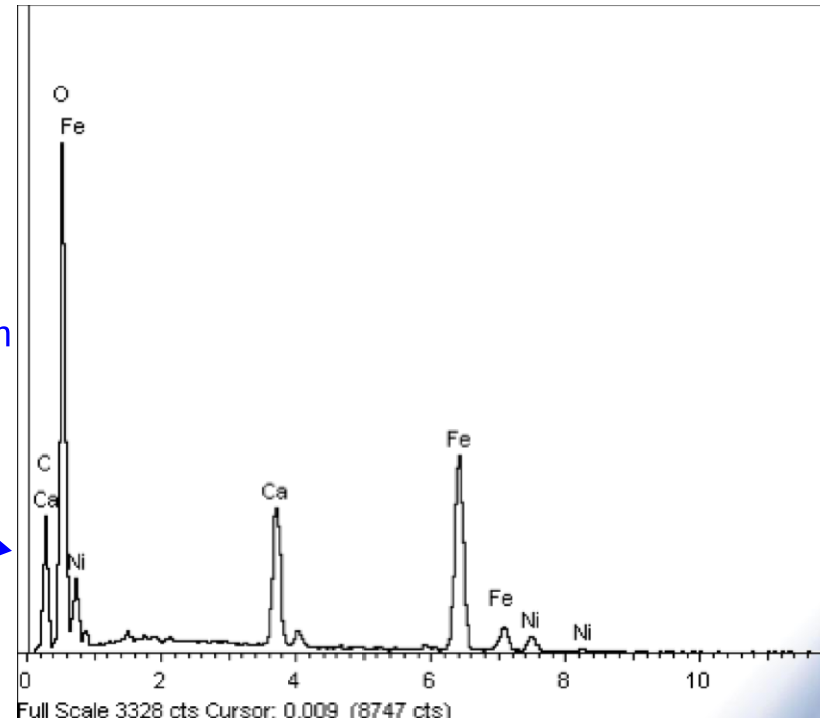
28-30.5cm

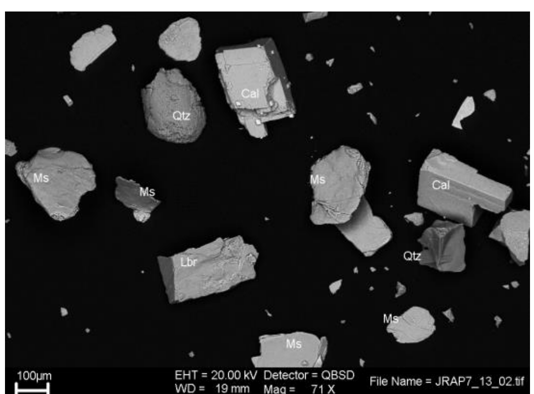
Faces etched



33-35.5cm

Fe-rich Phase





68-70.5cm

EDXA of secondary phase.

Morphology resembles the starting material.
Some evidence of etching is still observed.

Calcite XRD and TGA