Metal content mobilisation from deep ore bodies

Chris Rochelle, British Geological Survey

On behalf of the CHPM2030 Work Package 2 scientists from the:
University of Szeged, Hungary; University of Miskolc, Hungary;
ISOR, Iceland; VITO, Belgium; and the BGS, UK

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 654100.

The challenge

1) EU needs clean energy & to reduce import dependency → enhanced (or engineered) geothermal systems (EGS), but operating costs are high.
2) EU requires critical raw materials (limited domestic accessibility/mining) → may exist at depths beyond those targeted by commercial exploration/extraction.

Combined Heat, Power and Metal extraction from ultra-deep ore bodies: WP2

The concept

Identify hot rocks with ultra-deep (>4km) metalliferous mineralization

↓

Establish an EGS

↓

Enhance the existing fracture systems in the orebody

↓

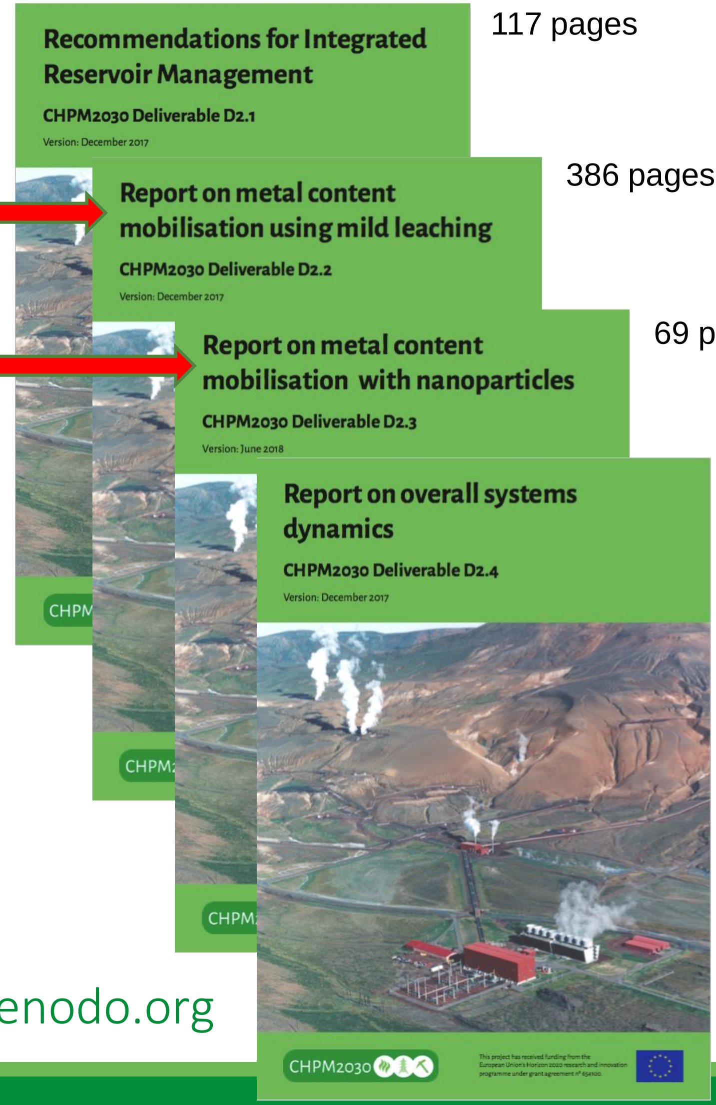
Leach metals from the orebody

↓

Extract metal from the brine

↓

Produce heat and electricity



117 pages

386 pages

69 pages

28 pages

https://zenodo.org

Our specific challenges and approach

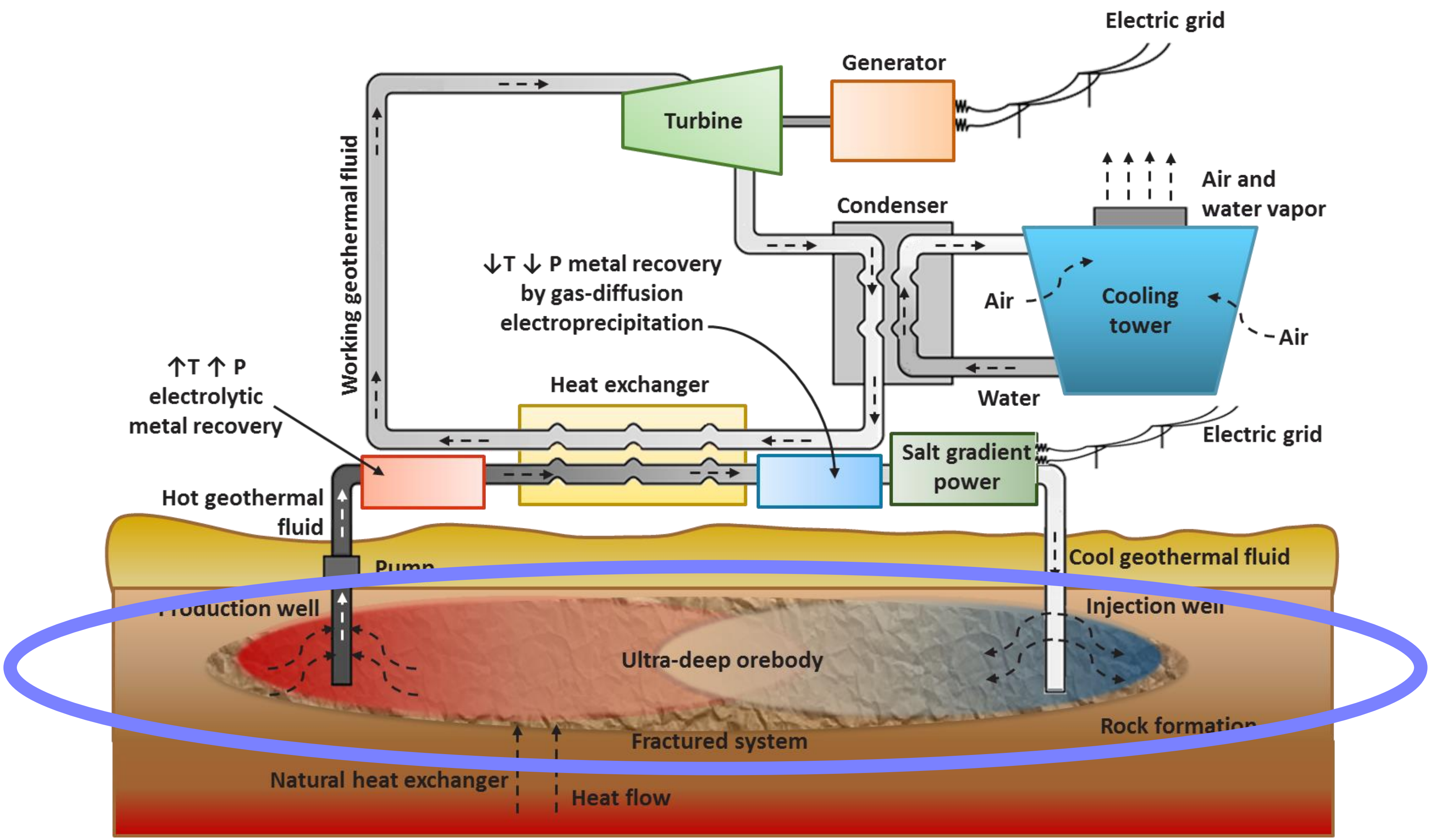
To investigate whether:

- Metals can be leached in sufficient concentration and over a prolonged period to influence the economics of EGS *.
- Continuous leaching of metals will increase system performance over time without the need for high-pressure reservoir stimulation.
- The composition/structure of orebodies is advantageous for development of EGS.

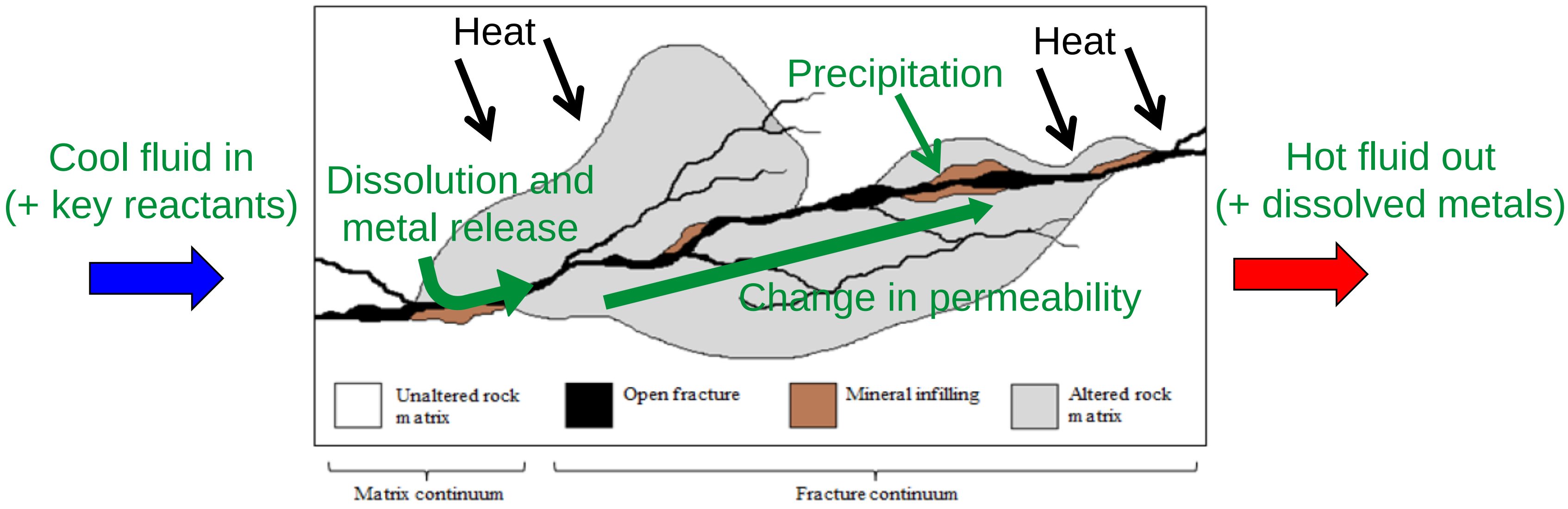
And to:

- Test and demonstrate proof-of-principle for in-situ leaching techniques using simulations and laboratory experiments.

Component of study: The subsurface



Component of study: The subsurface

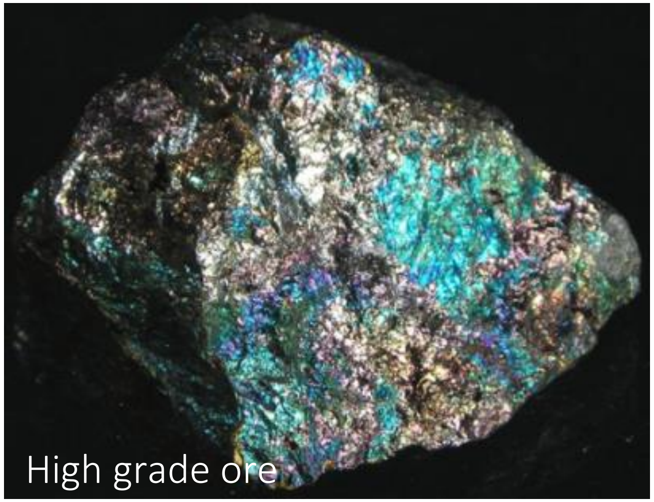


Metals in minerals lining fractures were originally deposited from fluids. We are thus looking at the potential for the reverse of this process.

We have been investigating this process through a largely experimental programme, but combined with some modelling.

Metallic mineral distribution

The project concept is for metals to add to the economics of an EGS, rather than be the primary driver.
Thus lower degrees of mineralisation can be considered compared to a 'classical' mineral deposit.



versus

12 metal-rich samples from the 4 European study areas were used in this study, although most work was done on ores from the UK.

Metal mobilisation

Experimental work aimed to address several knowledge gaps:

- Can relatively benign fluids be used to enhance metal leaching? If so, what concentrations and release rates can be expected?
- Can these metals be kept in solution, so that they can be successfully recovered at surface?
- Investigate whether fluid-rock reactions have the potential to increase permeability, rock surface area, and to increase both heat extraction and metal leaching?
- What is the risk of precipitation/scaling in the reservoir/surface infrastructure?

We investigated the above using 'conventional' solution-based approaches, and also the potential use of carbon (nano)particles.

Laboratory leaching/dissolution experiments

Start simple and build complexity

Multiple fluids: 70°C, 1 bar (>34 expts,)

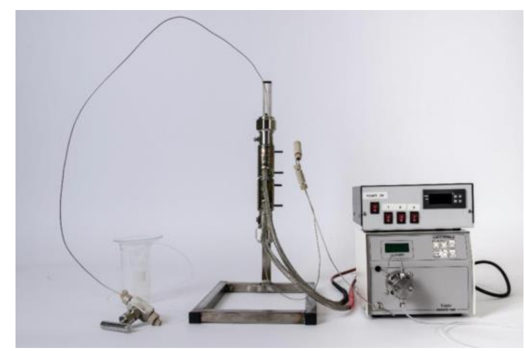
Promising fluids: 100-150°C, 200 bar

Best fluids: 200+°C, 200 bar

>36 expts

Fluids tested (relatively ‘mild’ leaching agents):

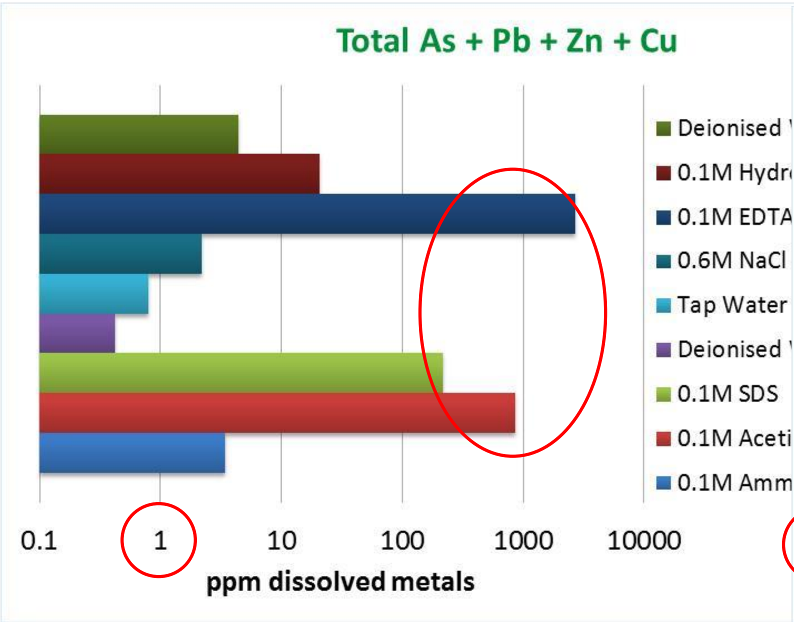
- De-ionised water & tap water (base cases)
- 0.6M NaCl brine
- Carbon dioxide saturated fluids (enhanced acidity)
- Dilute (0.1M) fluids:
  - Acetic acid (weak acid, complexing agents)
  - Dilute ammonia (weak alkali, complexing agent)
  - EDTA (‘classic’ complexing agent)
  - Sodium Dodecyl Sulphate (SDS) (surfactant & complexing agent)
  - Hydrogen peroxide (oxygenating, acid generating)

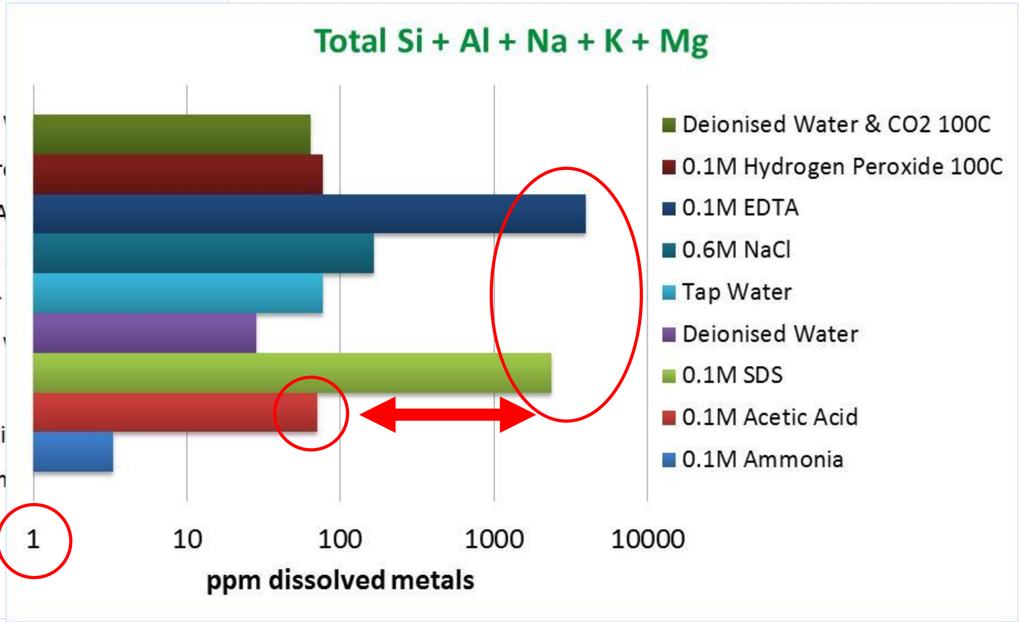


Flow-through expts 250°C, 250 bar

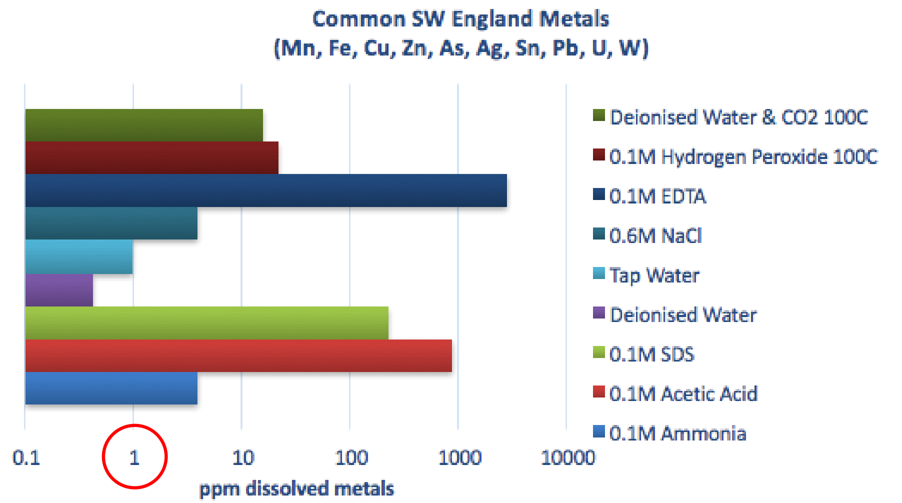
Leaching tests: summary of results

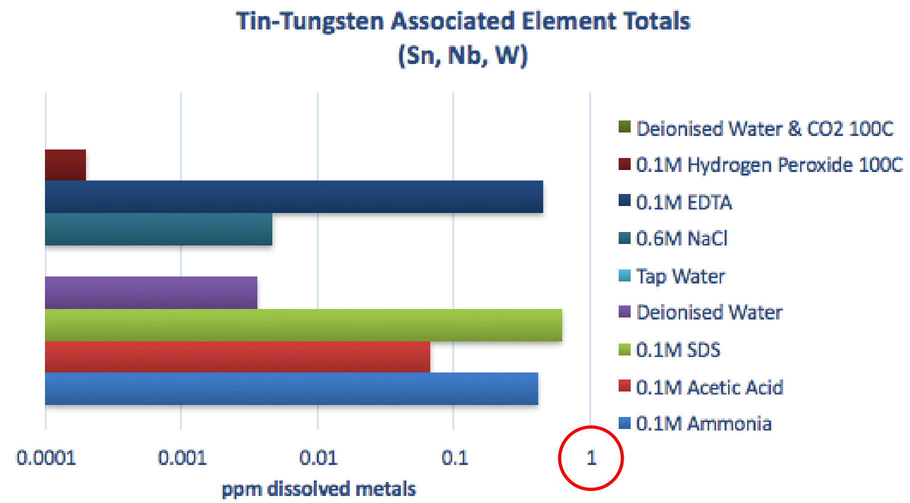
- Achieved enhanced mobilisation of metals.
- Group similar elements to demonstrate overall performance.
- Tap-water & deionised water were the poorest performing fluids (addition of CO_2 improved leaching, but was generally restricted to base metals).
- Dilute EDTA, SDS and acetic acid (organics) were the best performing fluids.
- Most fluids dissolved elevated concs (10s-1000s ppm) of elements derived from silicate minerals → implications for permeability of the EGS reservoir.

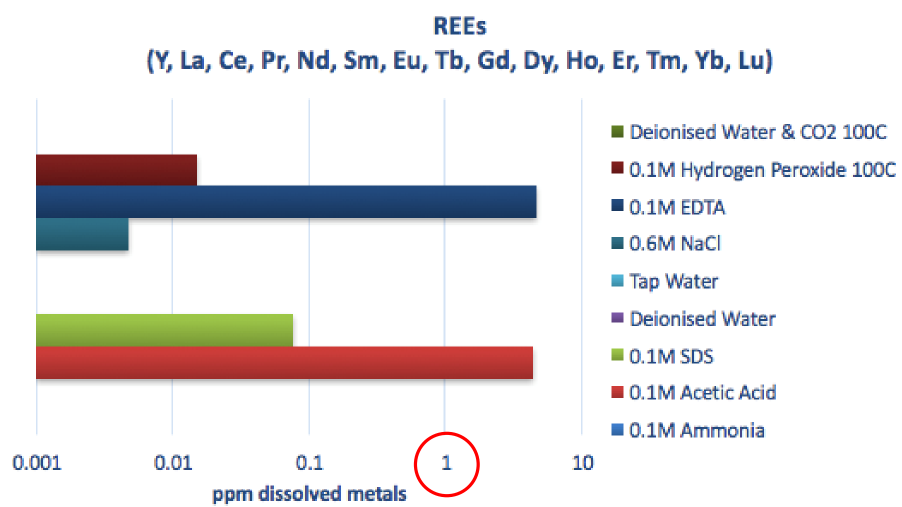


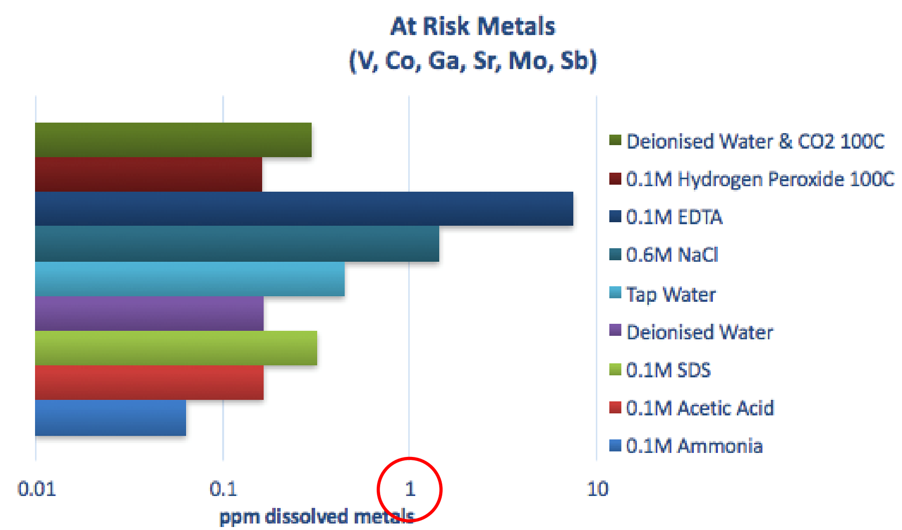


Leaching tests: summary of results



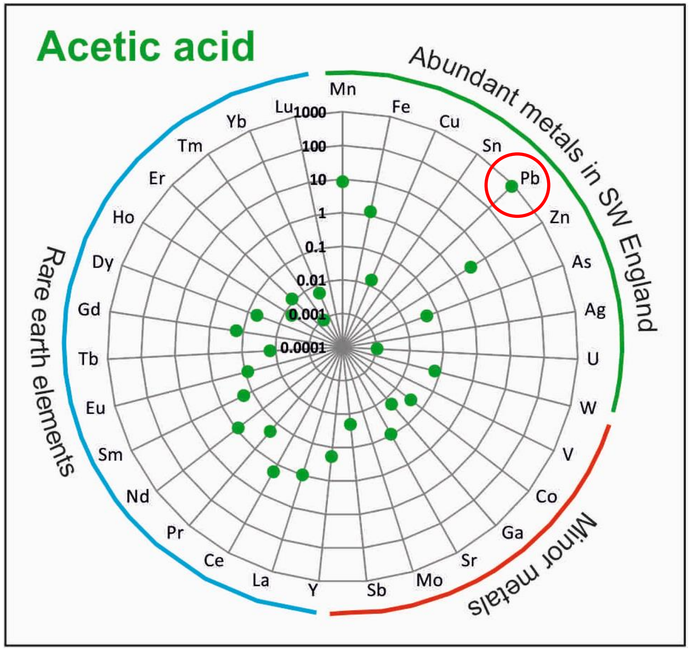


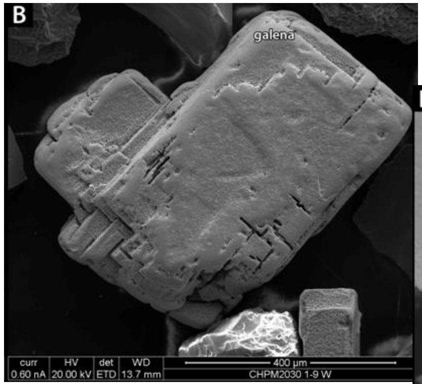


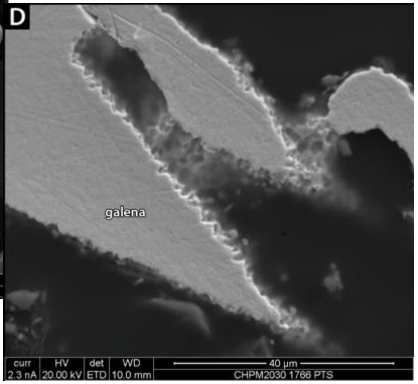


Leaching tests: summary of results

- Metal release aided by higher temperatures, lower pH, presence of ligands.
- Also favoured by the presence of (chalco)pyrite (possible control of oxidation reactions by $Fe^{3+}_{(aq)}$).
- Ag & Cu reprecipitated around etch pits in galena (possible competition for ligands).
- Some precipitates grew, but other minerals were released as fines (e.g. Mg borates from carbonates).
- (Also noted corrosion of Ti equipment in some tests).



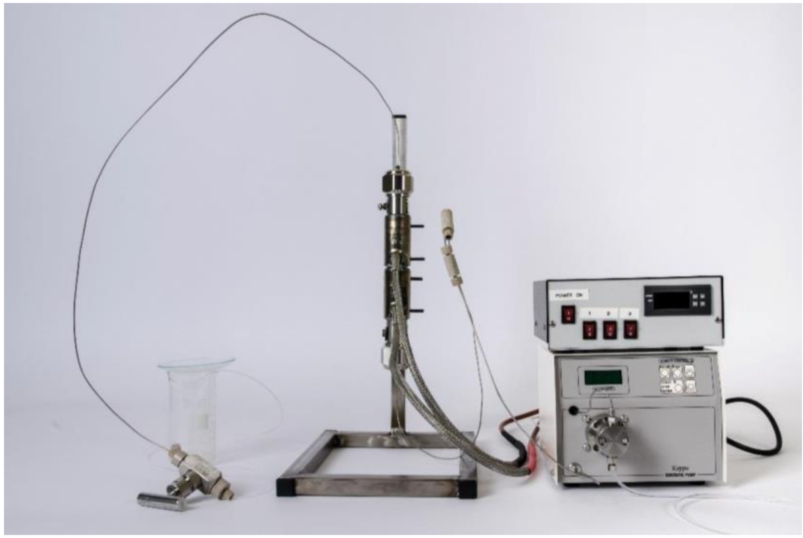




Etch pits in galena after leaching tests

Leaching tests: summary of results

- Utilised a high pressure/temperature reactor to measure metal release in a flow-through system and determine soluble metal content (for fresh mineral surfaces achieved c. 20 ppm Pb in 30 mins, but also enhanced Zn and Li).
- We should be cautions in projecting flow and solution chemical parameters to a metal recovery pilot site. But a (low) flow rate of 40 L/sec, gives production estimates in the order of several kg/day. *



Metal content mobilisation with nanoparticles

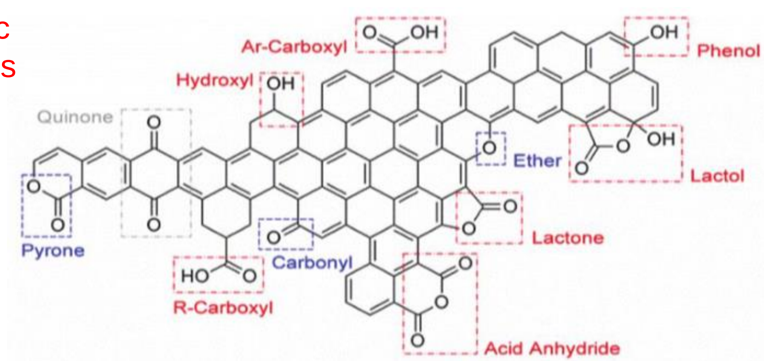
Objectives:

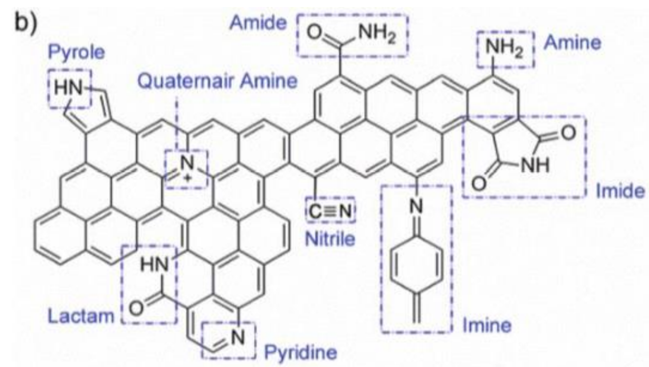
- Investigate whether functionalised carbon nano-particles can be used to enhance metal mobilisation.
- Select and screen commercially-available carbon nano-materials for metal mobilisation.
- Modify selected materials to improve selectivity.

Nanoparticles: summary of results

- 4 promising C-based materials had their properties characterised using a variety of surface / gas adsorption techniques.
- Treated 2 of them with acids and alkalis to modify their properties, and target a wider range of metals and pH conditions.

Acidic groups





Alkaline groups

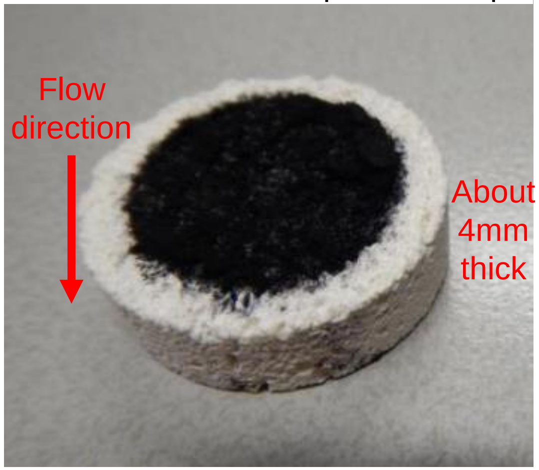
- Initial metal uptake tests used Zn^{2+}. But given the strategic importance of REEs, the focus moved to Nd (as a ‘typical’ REE).
- The best performance was >90% adsorption.
- Functionalisation changed performance, in some cases allowing adsorption to occur over a broader range of pH.

Nanoparticles: summary of results

- Investigated selectivity, and still had a ~40% sorption capacity for Nd with 1000 ppm Pb, though this dropped to 20-30% as temp. and salinity increased (80°C, 0.5 M NaCl).
- Less expected was the response of the nanoparticles to porous materials. Even though the particles were smaller than the pore sizes in the test disks (ceramics with a very uniform pore size and permeability = simulated rock), a layer of particles built up at the surface and overall permeability dropped dramatically.

Sample holder for permeability tests

Carbon particle layer built up on surface of porous sample



Metal mobilisation: Observations

Positives:

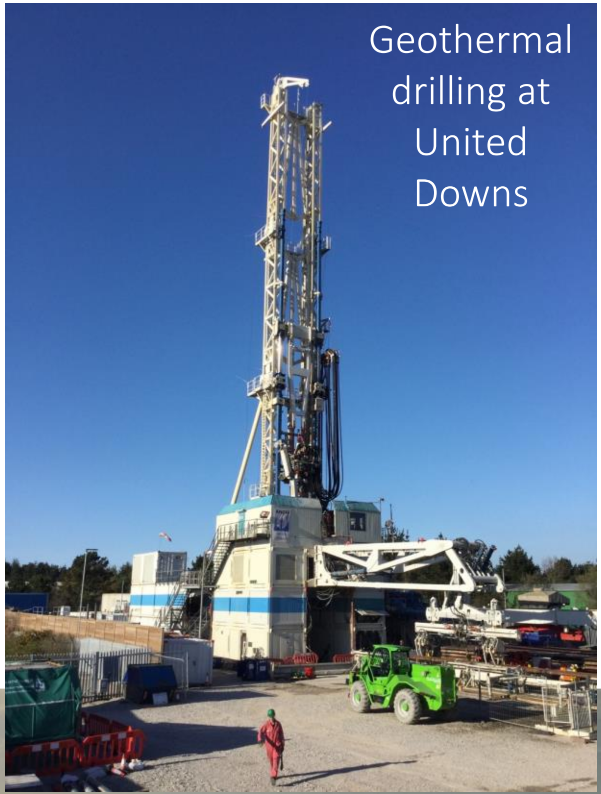
- There was evidence of enhanced metal leaching into solution - especially for sulphide mineral elements (e.g. Pb, Zn), but also Li.
- Metal release was controlled by mineral dissolution rates, a process which could be enhanced by a range of redox reactions - in particular, oxidation by Fe^{3+} from Fe-rich sulphides.
- There was evidence for some selectivity by using specific leaching agents, a step towards targeting specific metals.
- Carbon-based nano-materials did show enhanced abilities to sorb dissolved metal ions, and also some selectivity.
- (Linked rock physical properties studies indicated improvements in fluid flow and fluid-rock reactions near microfractures.)

Metal mobilisation: Observations

Challenges:

- The need to transition from process-oriented studies (mainly at lab-scale), to real systems at field scale.
- Key data are scarce from the 4-5 km depth of interest. We need new site-specific data to turn generic models into focussed ones.
- Need for in-situ fluid chemistry: Informs estimates of ligand concentrations, and hence overall metal mobilisation.
- Though some metals were released, many strategically-valuable metals (re)precipitated and/or remained at low concentrations.
- Need to study further the impact of matrix dissolution and potential secondary phase precipitation on permeability.
- Though C-based nano-materials showed promise for mobilising less soluble metals, we need to understand why they did not move thorough the simulated porous rock.

Thank you
for your attention



Geothermal drilling at United Downs

Sunrise in Falmouth, Cornwall, UK