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Gateway to the Earth

Enhancing metal leaching in geothermal systems

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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.

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

The concept

Identify ultra-deep 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

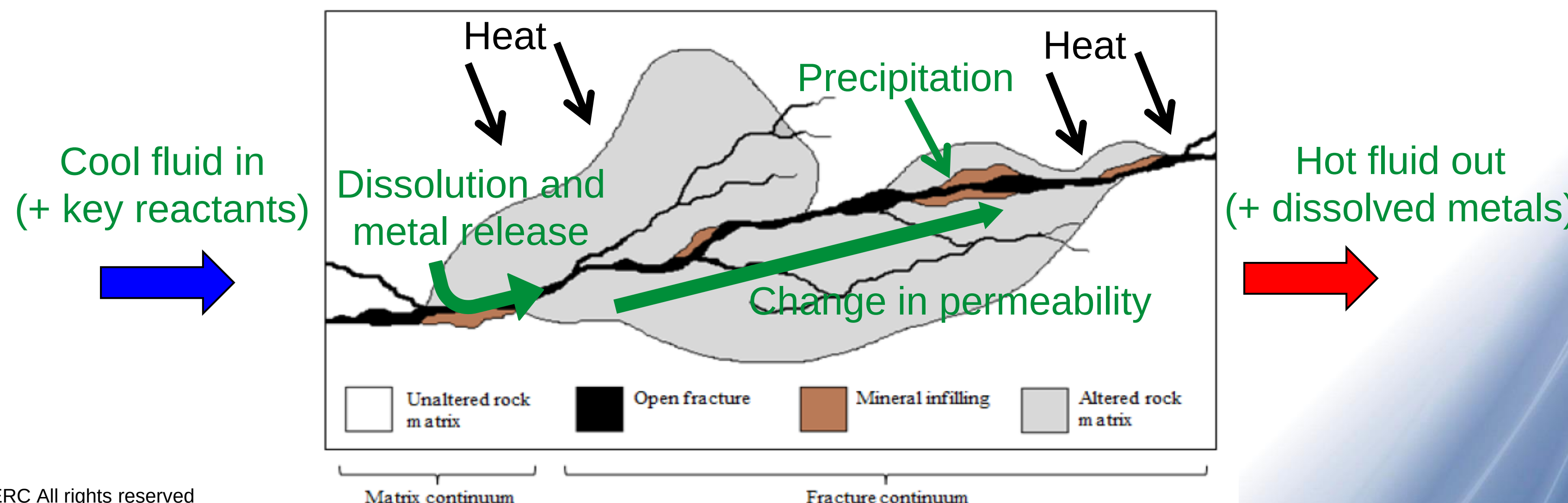
The hypothesis

- The composition/structure of orebodies is advantageous for development of EGS
- Metals can be leached in sufficient concentration and over a prolonged period
- Continuous leaching of metal will increase the systems performance overtime without the need for high-pressure reservoir stimulation

Enhanced metal leaching in geothermal systems

Experimental work aims to address several knowledge gaps:

- Can relatively <u>benign fluids</u> be used to enhance metal leaching?
  - what metal <u>concentrations</u> and <u>release rates</u> can be expected?
- Can these metals be <u>kept in solution</u>, so that they can be successfully recovered at surface?
- Will mineral dissolution enhance reservoir permeability in the EGS?
- What is the risk of precipitation/scaling in the reservoir/surface infrastructure?



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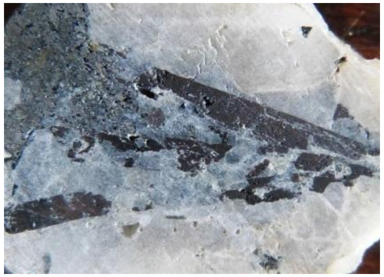
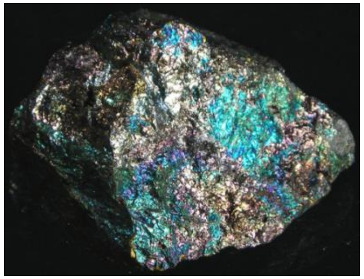
Laboratory experimental studies

- **Samples:** Ores from the UK (e.g. Herodsfoot [Pb-Ag-Sb]), plus also Europe.


- **Fluids tested** (to date):
  - De-ionised water & tap water (base cases)
  - 0.6M NaCl brine
  - CO_2-saturated fluids (enhanced acidity)
  - Dilute (0.1M) fluids:
    - Acetic acid/Ammonia (weak acid/alkali complexing agents)
    - EDTA ('classic' complexing agent)
    - Sodium Dodecyl Sulphate (SDS) (surfactant & complexing agent)
    - Hydrogen peroxide (oxygenating, acid generating)

Multiple fluids: 70°C, atmospheric pressure →

Promising fluids: 100-150°C, 200 bar →

Best performing fluids: 200°C, 200 bar →

Flow-through, 200°C, 200 bar

Experimental approach

Sample ID.	Description	Deionised Water	Tap Water	0.6M NaCl			0.1M SDS	0.001M SDS	0.1M EDTA		0.001M EDTA	0.1M Acetic Acid		0.001M Acetic Acid	0.1M Ammonia	0.001M Ammonia	0.1M H2O2	CO2 Rich Water	0.1M HNO3, 0.03M HCl		Coke
		70°C	70°C	70°C	100°C	150°C	70°C	70°C	70°C	150°C	70°C	70°C	150°C	70°C	70°C	70°C	100°C	100°C	100°C	200°C	150°C
CHPM 4	Carbonate hosted lead-zinc mineralisation (Hungary)				X														X		
CHPM 5	Quartz porphyry mineralisation (Hungary)				X														X		
CHPM 12	Lead sulphide mineralisation (Romania)				X														X		
CHPM 18	Skarn material (Romania)				X														X		
CHPM 20	Quartz porphyry mineralisation (Sweden)				X														X		
CHPM 26	Sulphide mineralisation (Portugal)				X														X		
BGS 319	Tin-tungsten mineralisation (Cornwall)	X	X	X	X		X	X	X		X	X		X	X	X	X	X			
BGS 315	Polymetallic mineralisation (Cornwall)	X	X	X	X		X	X	X		X	X		X	X	X	X	X			
CHPM 8	Meta-Sed hosted sulphide mineralisation (Cornwall)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Most (scoping) tests on UK material (3 lower rows, range of P, T, solutions).

But also 100°C tests on 6 samples from elsewhere in Europe.

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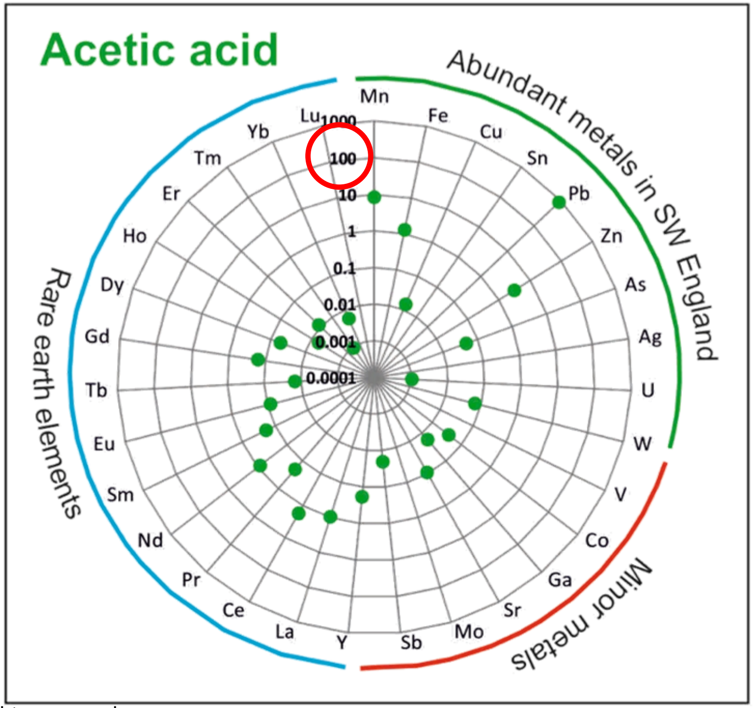
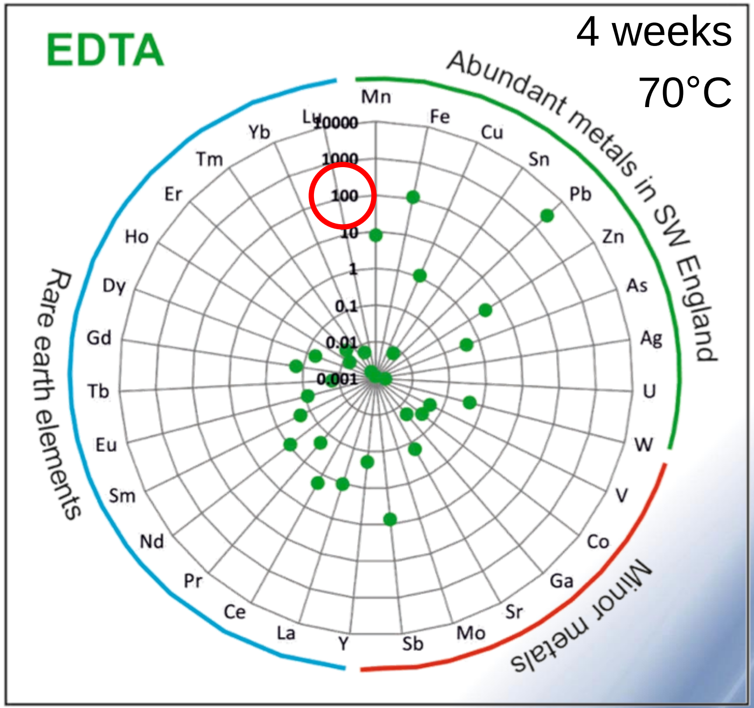
Preliminary results: leachate chemistry 1

Leachate metal concentrations:

- Tap-water & deionised water: poorest performing fluids (addition of CO_2 improved leaching, but generally restricted to base metals).
- More effective fluids leach a wide range of metals.
- Best performing fluids: dilute EDTA, SDS and acetic acid (organics): 100-1000s ppm base metals & liberate some minor or ‘critical ’ metals.





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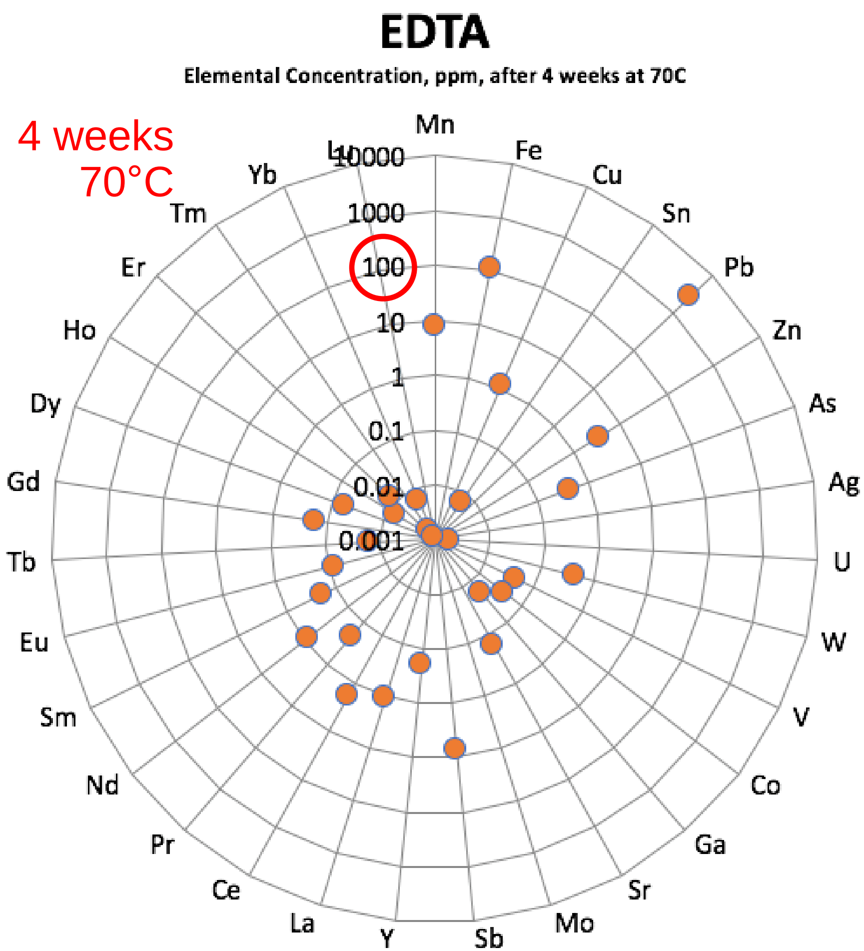
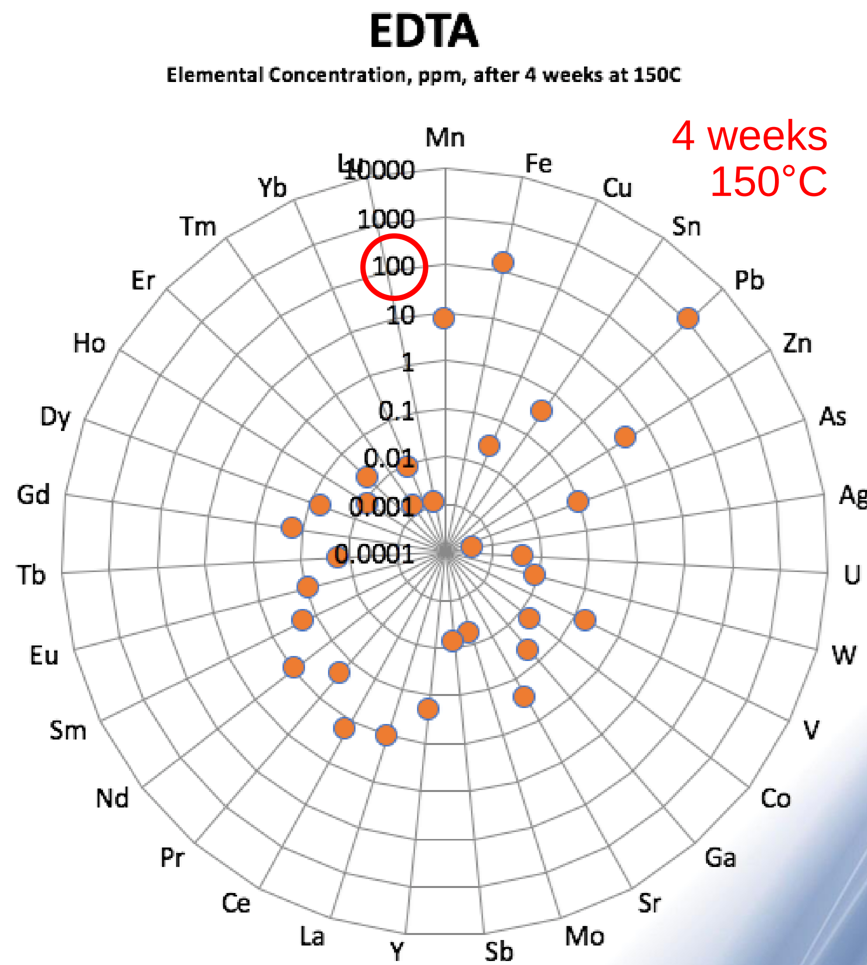
Preliminary results: leachate chemistry 2





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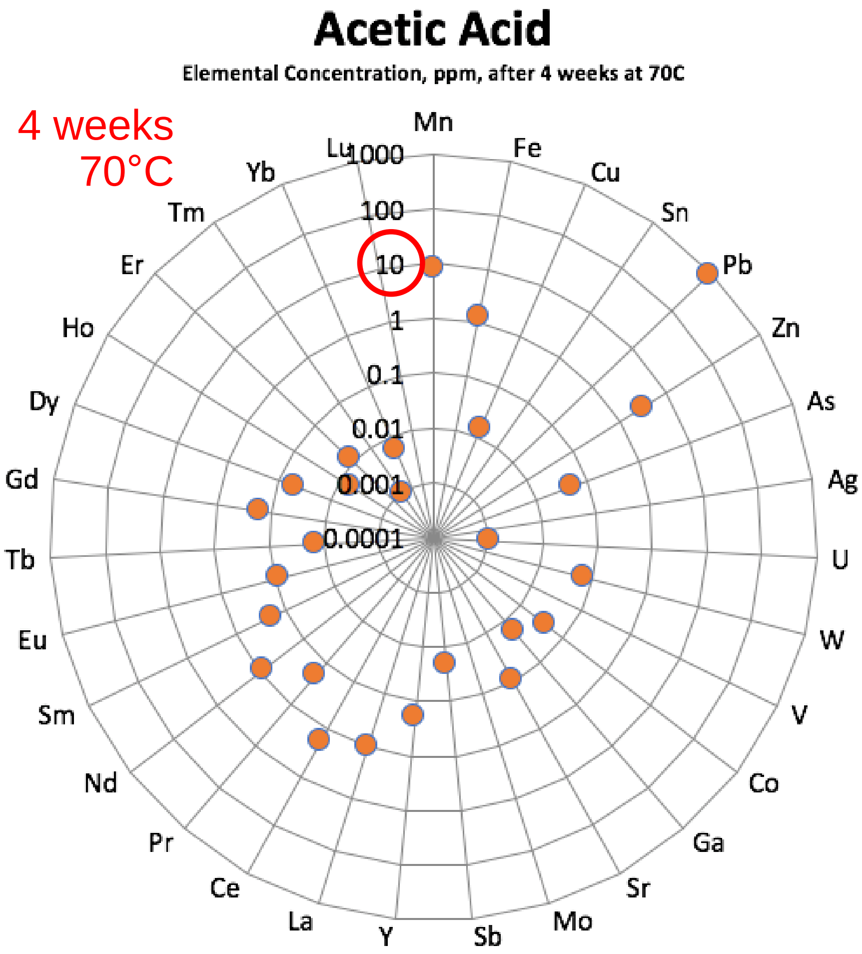
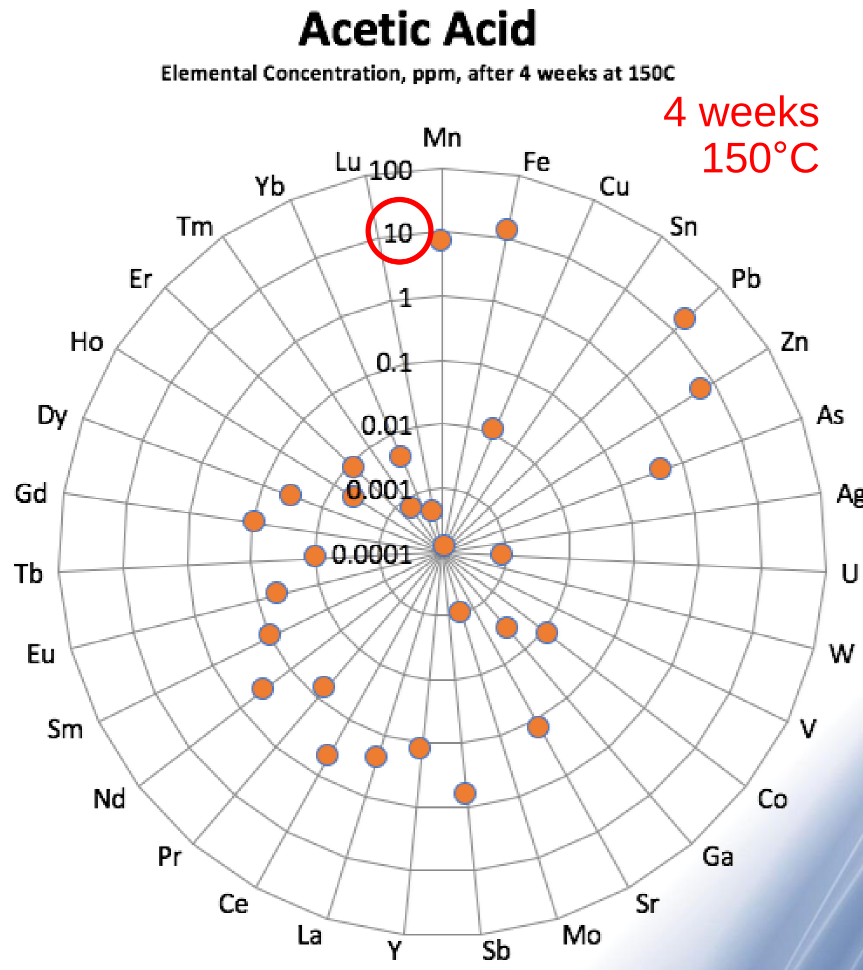
Preliminary results: leachate chemistry 3





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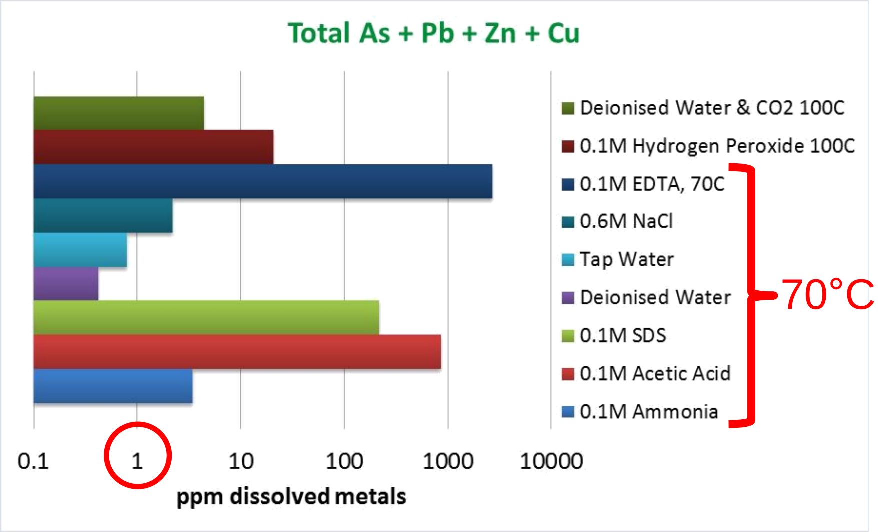
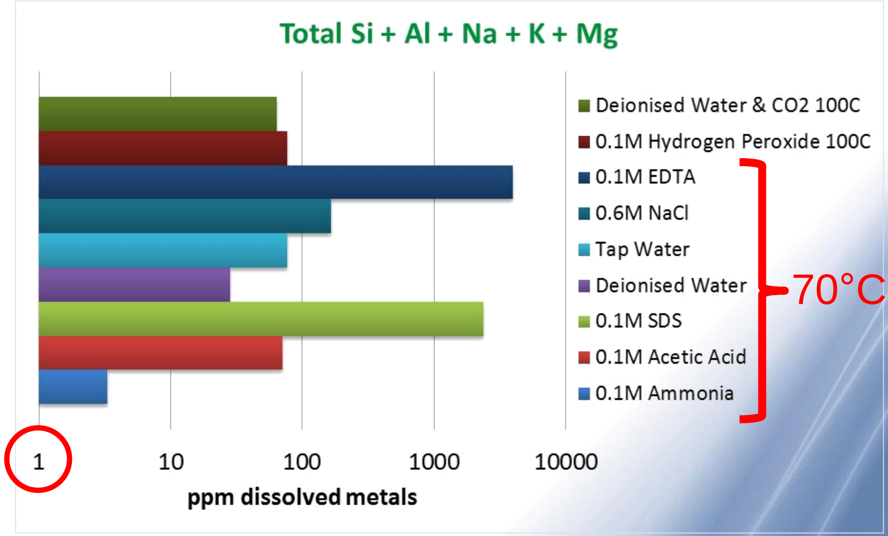
Preliminary results: leachate chemistry 4

Comparing leachate performance:

- Group similar elements to demonstrate overall performance.
- Tap-water & deionised water were the poorest performing fluids.
- Dilute EDTA, SDS and acetic acid (organics) were the best performing fluids.
- Some metals (e.g. Ag) possibly being <u>leached and then re-precipiated</u>.
- Most fluids dissolved high loads (10s-1000s ppm) of elements derived from silicate minerals → <u>implications for permeability of the EGS reservoir</u>.





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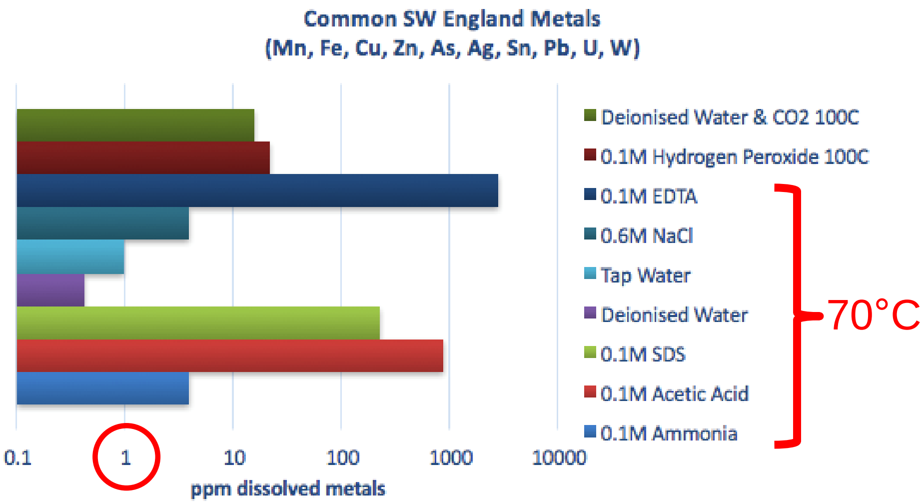
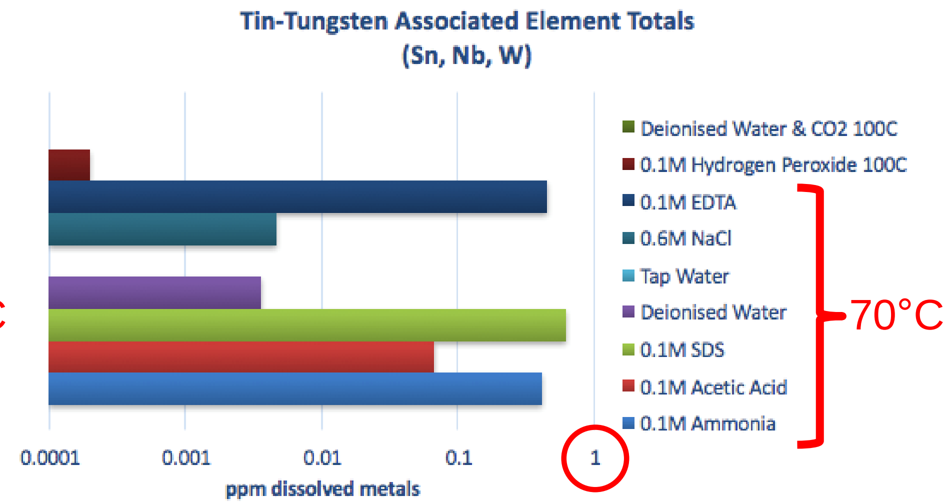
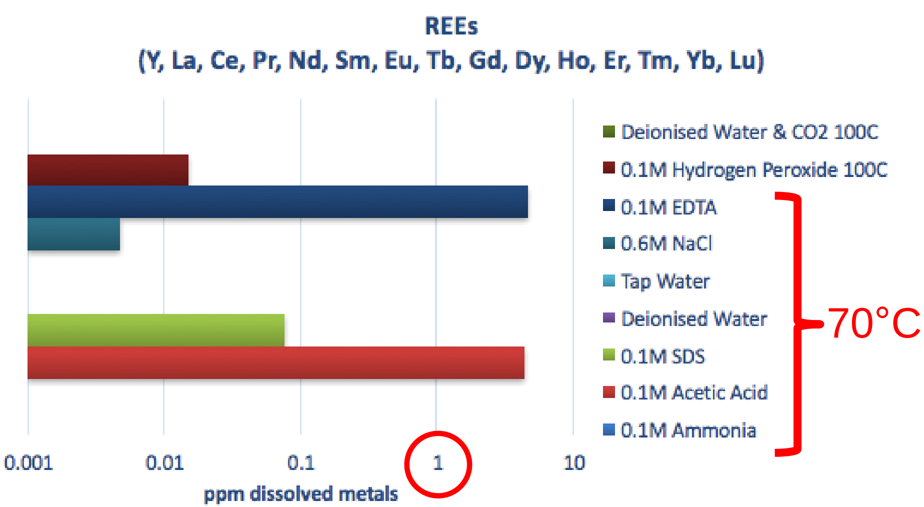
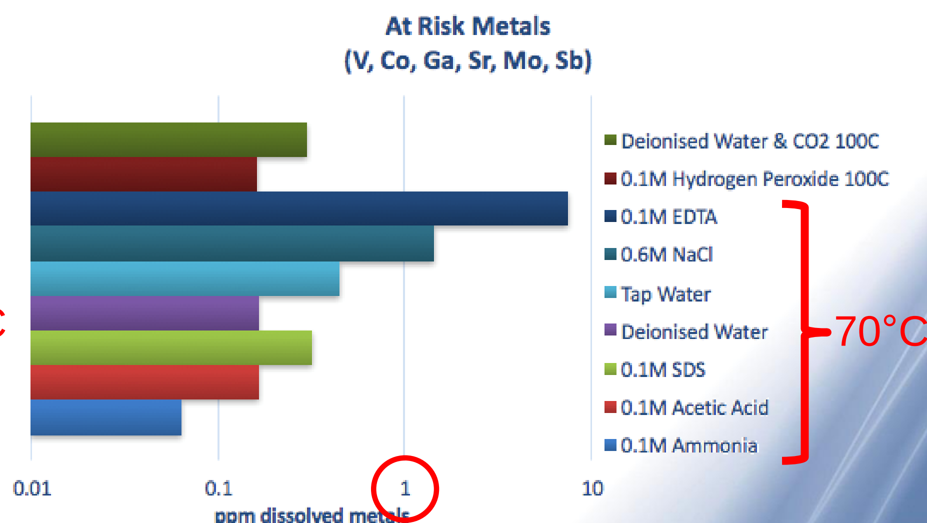
Preliminary results: leachate chemistry 5









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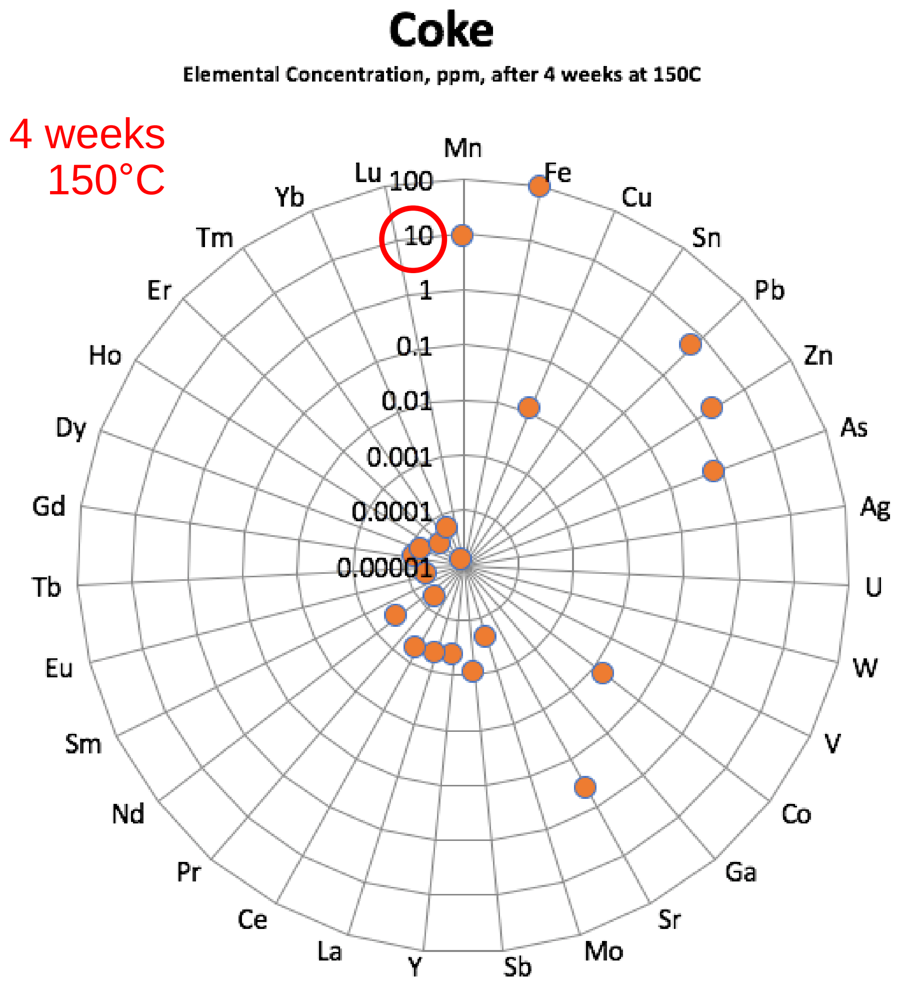
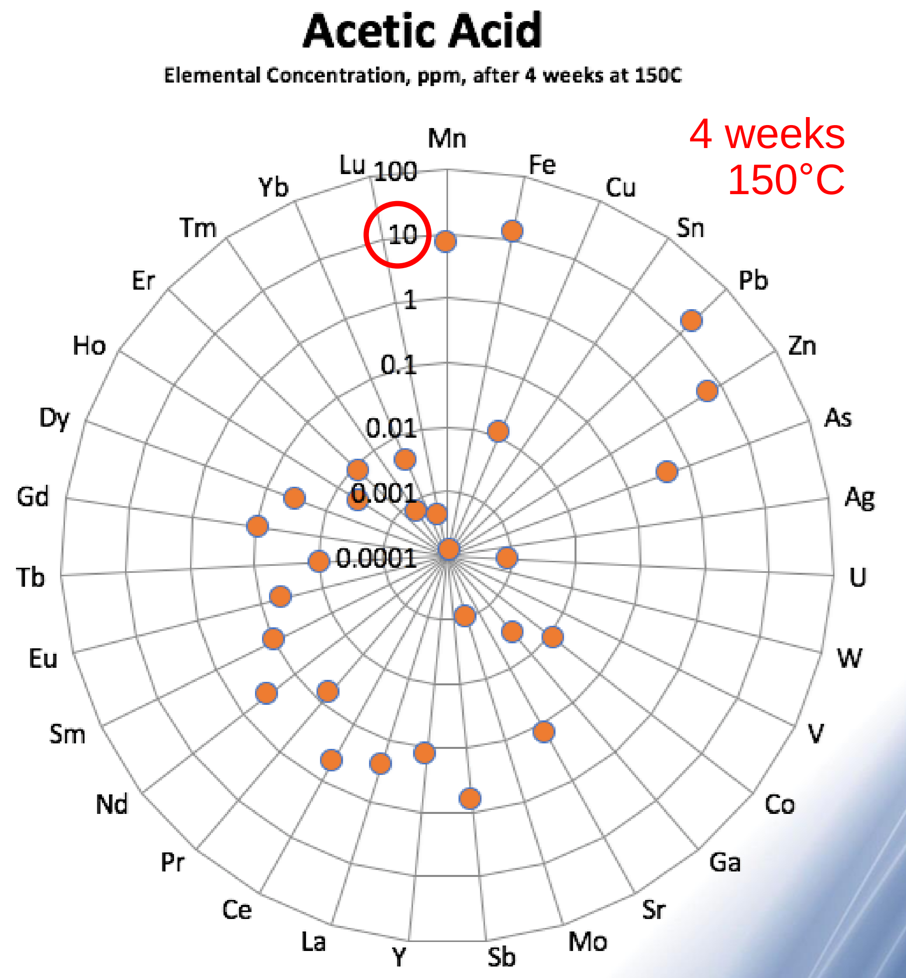
Preliminary results: leachate chemistry 6





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Summary and future work

- The ongoing CHPM2030 project investigates whether EGS take-up can be enhanced by adding a second revenue stream (metals) to heat energy.
- At the BGS we have been studying whether metal concentrations can be enhanced via additives in the recirculating fluid; data for some metals are promising, others less so.
- We are currently investigating:
  - Increasing temperature and contact time.
  - Utilisation of stronger, 'mineral' acids (diluted HCl, HNO_3) or a combination of fluid types.
- Reprecipitation of desirable elements in-situ may happen, possibly necessitating occasional modification to the fluid and 'flushing' of the system to mobilise these desirable metals.
- The impact of matrix dissolution and potential secondary phase precipitation on permeability is uncertain, and we will quantify this in future flow-through experiments.

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