How does fluid mixing in carbonate systems impact the formation of critical mineral deposits?

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Project Highlights:

- Establish the role of subsurface fluid mixing on critical mineral deposition in sediment-hosted ore deposits.
- Use novel in-situ mineral scaling test methodology established in Engineering to answer to decipher a geoscience question of high importance for enabling the energy transition
- Develop in-depth understanding of mineralisation kinetics for carbonate-hosted ore deposits in, and the direct vicinity of, fluid mixing zones such as fault zones.

Overview: (340 words)

Major deposits of critical minerals and metals such as copper, cobalt, lead, and zinc commonly occur within, or in the direct vicinity of faults, fractures or other high porosity zones within carbonate deposits. This mineralisation can post-date the formation of the fault, fracture or high porosity zones, resulting in mineral-rich brines being mixed into existing fluids within these carbonate-hosted permeable networks. The resulting fluid mixing, and associated chemical exchange with surrounding carbonate rocks, creates disequilibrium within the system which can induce mineralisation. Fluid-rock interaction experiments show that as Ca content in the fluid increases, as it is dissolved from surrounding carbonates, it can act as a catalyst for Zn-Pb mineral precipitation [1] and create a buffering effect linked to sphalerite (ZnS) precipitation when mixed with H_2S-containing brines. These findings are consistent with the link between sphalerite precipitation from experiments investigating combined corrosion and scale in H_2S-geothermal systems [2]. Numerical modelling shows similar effects for baryte formation in carbonates [3].

This project addresses the fundamental scientific question: What role does the mixing of fluids of different chemistries in naturally occurring zones of high permeability play in the formation of carbonate-hosted ore deposits?

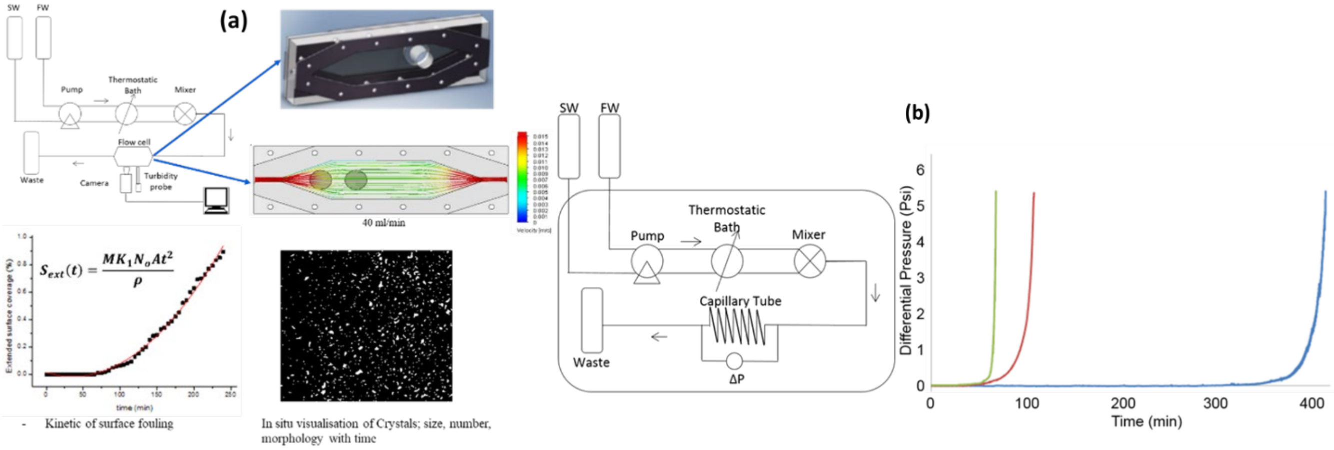

Figure 1: Example of (a) Dynamic In-situ Visualisation Flow cell with some of the results of precipitation kinetics and visual evidence of crystals, and (b) the dynamic tube blocking rig showing the change in pressure due to the mineralisation process.

The project builds on knowledge and techniques developed in the engineering community to study the phenomena of mineral nucleation when fluids are mixed, e.g. during operation of industrial systems such as geothermal power plants, oil and gas extraction and transport, and CCUS schemes [4, 5].

The student will combine state-of-the-art dynamic mineralisation test rigs (Fig. 1) allowing in situ assessment of mineralisation kinetics and fluid-rock batch experiments. Such rigs have been successfully used to simulate flow profiles and temperatures, and to track the mineralisation kinetics and deposition of different brine conditions ($BaSO_4$ and $CaCO_3$ forming brines) at low saturation levels [4, 5]. Targeted experiments will help to deliver qualitative and quantitative insights into the mineralisation phenomena. The project will lead to an in-depth understanding between fluid influx and mixing, mineralisation kinetics, pre-existing geological permeability networks, and their link to the occurrence of critical minerals.

Methodology:

Laboratory experiments: Dynamic mineralisation rigs will allow real-time analysis of the precipitates formed during fluid mixing. Experimental results will be fitted to a diffusion-controlled crystallization-based model to establish mineralization kinetics. Batch experiments will help to refine long-term behaviour. Brines will be sparked with trace elements important for critical minerals to monitor their incorporation in different ore minerals.

Analytical methods: Microstructural and microchemical analyses will be conducted on pre- and post-test samples at the University of Leeds (LEMAS, Bragg Centre for Materials Research), and the University of Liverpool SEM-Shared Research Facility. Samples will be analysed in SE, BSE, EBSD and EDS modes to document changes in phases, chemistry, porosity and growth evolution. Novel Time-of-flight-trace-element analysis will help to link ore mineralization to critical metals. AAS analysis will be performed on residual brine chemistry pre-post experiment to quantity the levels of free species linked to in situ mineralisation process.

Depending on the student's interest, experimental work will be supplemented with either detailed numerical modelling [e.g. 3] or field observations from up to 3 different ore deposits in the UK.

Possible Timeline

Year 1: Literature review, computational optimisation of the flow cell for specific fluid chemistries and species, the start of preliminary experiments and analysis to gain experience with the apparatus and establish a baseline for further tests; natural sample collection; presentation at a national conference. Optional: Field work of carbonate hosted deposits.

Year 2: Main phase of the project, repeatable experimental work; including fluid chemistry analyses; precipitation kinetics; preliminary data analysis; presentation at an international conference; and preparing for first publication. Optional: Field work in carbonate hosted deposits / numerical modelling set-up and first analyses

Year 3: Finish experimental work and numerical / field work; further analysis; write up manuscript for second publication; write up the thesis.

Training and skills:

TARGET researchers will participate in a minimum of 40 days of training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*.
- an annual all-TARGET workshop with cross-year interactions, advanced training, and opportunities to specialise in particular areas of need in alignment with their work scope – *all years of study*.
- several one-day workshops.
- online events and in-person workshops attached to relevant conferences.

Specialist training in ore mineralisation-related laboratory experiments, fluid chemistry, microstructural analysis, and if needed, numerical modelling or field analysis, will be provided. This includes experimental fluid-mineralization techniques, microstructural/microchemical analysis on the SEM, field-based structural geology, or numerical modelling, and detailed mapping scanline surveys and oriented sample collection (with permissions). Laboratory training will include sample preparation, machine calibration, fluid and mineral precipitate testing and experimental data analysis. Numerical modelling will foster an open data approach to software development and publication. The student will be encouraged to present their work at national/international conferences and given support to submit publications to peer-reviewed journals.

Partners and collaboration (including CASE):

The project is hosted at the University of Leeds, with a supervisory team (Pessu, Piazolo and Healy) highly experienced in mineral scaling, particularly in sub-surface geothermal and CCUS context (Pessu Google Scholar), mineral-fluid reactions (Piazolo) and rock permeability and porosity (Healy). The co-supervisor and project partner at the University of Liverpool, McNamara, is an expert on the links between structure, mineralisation, and fluid flow and their expression in the field and microstructures. Several reciprocal day and 3* 1 week visits of the student to Liverpool are planned to ensure integration.

Further reading:

1. Liu, W., et al., *How carbonate dissolution facilitates sediment-hosted Zn-Pb mineralization.* Geology, 2021. **49**(11): p. 1363-1368.
2. Frank, O. and F. Pessu. *Effect of Zn2+ and Pb2+ on the Corrosion of Carbon Steel in Sulphide Scale Forming H2S – Containing Environments*. in *AMPP Annual Conference + Expo*. 2024.
3. Koehn, D., et al., *Outcrop scale mixing enhanced by permeability variations: the role of stationary and travelling waves of high saturation indices.* Geological Magazine, 2022. **159**(11-12): p. 2279-2292.
4. Sanni, O., et al. *Study of Surface Deposition and Bulk Scaling Kinetics in Oilfield Conditions Using an In-Situ Flow Rig*. in *CORROSION 2015*. 2015.
5. Bukuaghangin, O., et al., *Kinetics study of barium sulphate surface scaling and inhibition with a once-through flow system.* Journal of Petroleum Science and Engineering, 2016. **147**: p. 699-706.

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply.

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