Volatiles in zircon-hosted inclusions as indicators of porphyry copper fertility

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Project Highlights:

- Develop laboratory methods for measuring volatile concentrations in melt inclusions in zircon
- Constrain the evolution of volatiles in magmas before and during the formation of world-class porphyry Cu deposits
- Test for differences in the volatile and metal budgets of magmas forming deposits of differing endowment and/or grade

Overview:

Porphyry copper deposits are the main source of society's copper and account for large amounts of molybdenum, gold and other metals. These deposits form through the exsolution of metal-charged fluids from arc-related magma reservoirs. High concentrations of volatiles such as water, chlorine and sulfur are thought to play a key role in generating large porphyry deposits, as opposed to unmineralised magmatic systems (Grondahl and Zajacz 2022, Nathwani et al. 2024). However, determining volatile concentrations in porphyry-related magmas is challenging as most major mineral phases and melt inclusions are overprinted by hydrothermal alteration.

This project will develop methods to constrain volatile and metal concentrations in porphyry-ore forming magmas using melt and apatite inclusions in zircon. These inclusions are shielded from hydrothermal alteration and can therefore preserve important information on the evolution of porphyry-ore forming magmas (Nathwani et al. 2023, Butters et al. 2025). The new methods will be used to constrain the volatile and metal inventories in magmas in a world-class porphyry Cu district, where porphyry copper mineralisation occurs following millions of years of pluton formation without mineralisation. The results will help identify the key magmatic ingredients responsible for forming porphyry deposits. The developed methodology can also be deployed in mineral exploration to identify magmatic suites favourable for hosting porphyry mineralisation.

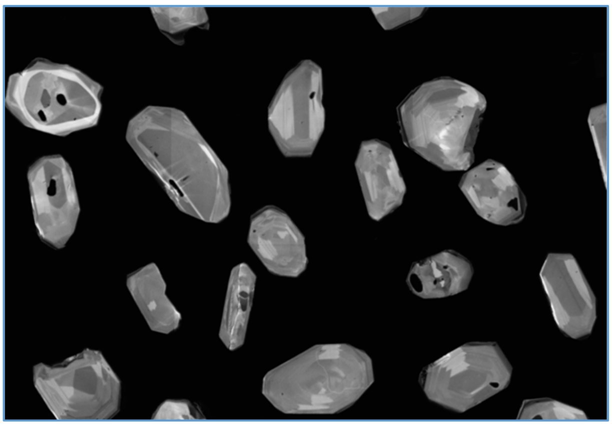

Figure 1: Zircon crystals from a porphyry copper deposit imaged using scanning electron microscope cathodoluminescence, showing frequent inclusions of melt and apatite within the crystals.

Methodology:

This project will use well-characterised sample suites from world-class porphyry copper districts, as well as poorly endowed porphyry deposits sampled from collections. Field sampling is anticipated to take place in the first year to complement existing sample suites from a case study site.

Geochronology using LA-ICP-MS U-Pb dating of zircon will constrain the ages of the investigated sample suite. LA-ICP-MS methods will be developed in collaboration with the Natural History Museum to determine volatile and metal concentrations in zircon-hosted melt inclusions. These results will be complemented by electron microprobe analyses to determine volatile concentrations in apatite inclusions in zircon. Experimental facilities at the University of Oxford will be used to better understand the behaviour of melt inclusions during heating. The results of the study will be synthesised using models of volatile evolution and degassing from magmas, to test the scenarios that best reproduce the measured volatile and metal concentrations.

Possible Timeline

Year 1: Literature review on volatiles in porphyry-related magmas and zircon-hosted inclusions. Selection of collection samples and visit to field area of case study site. Sample preparation and initial characterisation of zircon-hosted inclusions. Beginning of analytical work.

Year 2: Development of LA-ICP-MS methodology. Presentation of preliminary results at an international conference. Beginning of writing a paper on method development.

Year 3: Application of new methods to case study and collection samples. Interpretation of results using modelling approaches. Paper writing and presentation at international conference.

Training and skills:

Training in petrography and all analytical methods (electron microscopy, electron microprobe analysis, laser ablation) will be provided by the Natural History Museum, London and lab scientists. Training in experimental petrology will be available at the University of Oxford. Field skills and training in porphyry Cu deposit geology will be provided by the supervisors and attendance of a field training course (e.g. SEG) is encouraged. Graduate courses at Imperial College are available on a variety of these related to scientific research (e.g. data analysis, coding).

TARGET researchers will participate in a minimum of 40 days 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 – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

Partners and collaboration (including CASE):

The successful candidate will be primarily based at Imperial College London, with close collaborations with the Natural History Museum and the University of Oxford. The student will benefit from training and collaboration with laboratory staff at the Natural History Museum, London, providing access to a range of world-class analytical facilities. Partnership with the University of Oxford will provide access to experimental facilities and training in their use. The candidate will work closely with mineral exploration companies to access study sites, report findings, and engage in discussions.

Further reading:

Butters, D. *et al.* (2025) 'Transcrustal, volatile-charged silicic melts revealed by zircon-hosted melt inclusions', *Earth and Planetary Science Letters*, 655, p. 119252. https://doi.org/10.1016/j.epsl.2025.119252.

Grondahl, C. and Zajacz, Z. (2022) 'Sulfur and chlorine budgets control the ore fertility of arc magmas', *Nature Communications*, 13(1), p. 4218. https://doi.org/10.1038/s41467-022-31894-0.

Nathwani, C. *et al.* (2024) 'A zircon case for super-wet arc magmas', *Nature Communications*, 15(1), p. 8982. https://doi.org/10.1038/s41467-024-52786-5.

Nathwani, C.L. *et al.* (2023) 'Apatite evidence for a fluid-saturated, crystal-rich magma reservoir forming the Quellaveco porphyry copper deposit (Southern Peru)', *Contributions to Mineralogy and Petrology*, 178(8), p. 49. https://doi.org/10.1007/s00410-023-02034-8.

Park, J.-W. *et al.* (2021) 'Crustal magmatic controls on the formation of porphyry copper deposits', *Nature Reviews Earth & Environment*, 2(8), pp. 542–557. https://doi.org/10.1038/s43017-021-00182-8.

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply. Please contact lead supervisor Chetan Nathwani for further questions: chetan.nathwani@imperial.ac.uk