

Metal fluxes in volcanic arcs: An integrated minerals approach

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Project Highlights:

- Conduct and gain field skills in the Philippines
- Gain new analytical skills on state-of-the-art analytical instruments, including SEM, LA-ICP-MS and SIMS with widely applicable skills for future employment in academia and analytically focussed industries.
- Be part of the Centre for Sustainable Resource extraction to deliver vital solutions to the security of supply of metals for the 21st century.
- Work with an industry partner (Oxford Instruments) developing new applications for SEM techniques.

Overview:

Volcanic arcs play a key role in cycling metals such as Cu between the Earth's mantle, crust and atmosphere and are associated with some of our planet's most important economic deposits and commodities: porphyry copper deposits¹. In volcanic arcs, metal behaviour is governed by three different phases: 1) silicate melt and minerals; 2) sulphide melt and minerals; 3) volatiles (fluids and gasses)^{2,3}. The order in which these phases stabilise in a magma ultimately controls the cargo of metals concentrated into ore deposits. However, no single mineral is capable of simultaneously tracking the behaviour of all three of these potentially important phases. Hence, our ability to effectively quantify, trace, model and predict the cycling of metals is limited. Nevertheless, as minerals grow in a crystallising magma, they may trap inclusions of other phases that if analysed together, whilst retaining the textural context, allow us to determine the behaviour of all three phases in a single time slice. ***This project will use a multi-mineral, in situ approach, targeting apatite mineral inclusions to monitor volatile release and sulphide inclusions to track the behaviour of metals within the same zoned silicate hosts.***

Apatite, $\text{Ca}_5(\text{PO}_4)_3(\text{OH}, \text{F}, \text{Cl})$ is a common inclusion in phenocrysts and accommodates a number of volatile elements (mainly F, Cl and OH) through a series of exchange equilibria⁴. The partitioning of Cl into exsolved fluids in intermediate to evolved melts, means that volatile ratios in apatite are sensitive to the onset of volatile saturation, which is then also distinguishable from other magmatic processes such as fractional crystallisation that de-couple halogen ratios to a much lesser extent in apatite. **Sulphides** are a major repository for metals, including Cu, and are also commonly found as inclusions within the same zoned phenocrysts as apatite.

This work will focus on the Philippines. Pinatubo is a volcanic analogue to porphyry copper deposits, and is known to have apatite and sulphides in its phenocryst hosts. The unaltered nature of these materials makes them ideal. Samples from nearby porphyry deposits will then be compared using

mineral inclusions within resilient zircon hosts in order to compare key processes within the volcanic and porphyry systems.



Figure 1: Summit crater of Pinatubo – an analogous volcanic counterpart to porphyry copper deposits?

Methodology:

A combination of existing samples held at the UoL and new samples collected as part of a field expedition will be used for this study. Localities will include Pinatubo – a volcanic analogue to porphyry copper deposits and a number of porphyry mines in the Philippines, including Santo Tomas II and Dizon. Samples will then be processed and prepared (epoxy mounts, mineral separation and thin sectioning) at the UoL prior to in-house SEM and LA-ICP-MS analysis. Volatile measurements in apatite will additionally be made by direct measurement using SIMS following a successful application to the EIMF facility at the University of Edinburgh.

Possible Timeline

Year 1: Carry out a literature review of what is known about porphyry copper deposits and a minerals-based approach to investigating the magmatic processes responsible for their formation. Training in SEM and other microbeam analysis on the initial samples. Collect further samples from the Philippines. Attend a national conference.

Year 2: Continue mineral chemistry - presentation of results at international conference and initial publication. Plan application to EIMF facility.

Year 3: Complete analytical work. Carry full assessment of data. Publish papers on research and present at international conference.

Training and skills:

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.

Furthermore, training will be offered for fieldwork and analytical requirements.

Partners and collaboration (including CASE):

The applicant will benefit from the extensive expertise of the supervisory team:

- **Andrew Miles:** An igneous petrologist with over 10 years' experience in granite petrology, copper porphyry deposits, and mineral chemistry.
- **Dan Smith:** An internationally recognised expert on a variety of ore deposits and government advisor on critical metals.
- **Cees Jan De Hoog:** An authority in micro-analytical SIMS techniques and expertise in the 1991 Pinatubo eruption.
- **George Stonadge:** Completed a previous PhD on apatite from Pinatubo and associated pre deposits, with extensive expertise in micro-analytical techniques. Now works for Oxford Instruments.

The student will work closely with analytical specialists at Oxford Instruments in the UK, gaining experience in innovative analytical techniques valuable to both industry and academia.

Further reading:

1. Sillitoe, R., 2010. Porphyry copper systems. *Economic Geology*, 105, 3-41.
2. Stonadge, G., Miles, A., Smith, D., Large, S., Knott, T., 2023 The volatile record of volcanic apatite and its implications for the formation of porphyry copper deposits. *Geology*, 12, 1158-1162.
3. Holwell, D., Fiorentini, M., Knott, T., McDonald, I., Blanks, D., McCuaig, T., Gorczyk, W., 2022. Mobilisation of deep crustal sulfide melts as a first order control on upper lithosphere metallogeny. *Nature Geoscience*, 13, 1, 573.

Further details:

Please visit <https://target.le.ac.uk/> for additional details on how to apply. Please contact the lead supervisor, Dr Andrew Miles, with specific questions about the project: ajm131@le.ac.uk