Ore-forming processes in sub-volcanic systems

Supervisory Team

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Key Words: igneous petrology, experimental petrology, geochemistry, economic geology

This project is suitable for applicants with a training in igneous petrology, including field, laboratory, and theoretical skills. An interest in economic geology and thermodynamics is essential. Some training in geochemical modelling, microanalysis and experimental petrology is expected.

Overview

The transition to Net Zero presents many challenges for the energy and mineral resources sectors. New supplies of many metals will be needed to sustain the electrification of vehicles and to grow carbon-free energy generation, for example. One such metal is copper, which is widely used in power generation and distribution. Copper ore-formation is commonly associated with sub-volcanic systems, with porphyry copper deposits (PCDs) being the best-known and largest examples.

PCDs represent giant copper, sulfur and chloride anomalies in Earth’s crust. The sources of both elements are problematic in understanding PCD formation. The mass of copper in the largest PCDs (over 30 Mt contained Cu) requires derivation from a substantially greater volume of magma than is exposed in dyke rocks associated with deposits. This observation raises questions about the mechanism of efficient copper extraction from partially molten magmatic systems.

The case of sulfur is also puzzling, yet often overlooked. In most magmatic systems sulfur exists as a mixture of sulfide (S²⁻) and sulfate (S⁶⁺). In contrast, sulfur in volcanic gases exists as SO₂ (S⁴⁺) or H₂S (S²⁻). The majority of PCDs contain sulfide ore minerals, yet the dominant gas species in arc magmas, with which PCDs are associated, is SO₂. Thus, SO₂ reduction appears to be a pre-requisite for ore mineralisation.

Finally, the key ligand for transporting copper (and other metals) is chloride, which must be enriched in the mineralising hydrous fluids. Chlorine partitioning between magmatic fluids and melts is therefore crucial to metal transport.

These exacting requirements for the chemistry of ore-forming fluids are exacerbated by uncertainty as to how and where SO₂ becomes reduced to sulfide. Changes in pressure and temperature are one possibility; reactions between SO₂ and shallow magmatic fluids or rocks have also been proposed. Both cases involve disproportionation of SO₂ to form both sulfide and sulfate minerals following reactions such as:

\[ 4\text{SO}_2 + 4\text{H}_2\text{O} = 3\text{H}_2\text{SO}_4 + \text{H}_2\text{S} \]

Similar reactions, producing sulfide minerals instead of H₂S, can be written for reaction of SO₂ with igneous rocks or magmatic brines. Disproportionation can account for the widespread co-occurrence of copper sulfides and anhydrite in PCDs (figure). However, the driving force for disproportionation and the conditions under which it occurs are not well known. Nor is it clear if the ore-forming fluid contains the requisite quantities of both metals (as chloride species) and SO₂ or if an external SO₂ source is required. Finally, the role played by disproportionation in driving hydrolytic alteration reactions, characteristic of PCDs, is not known. This project will use geochemical calculations, high temperature and pressure experiments and field studies to address the broad problem of sulfide mineralisation and hydrothermal alteration in sub-volcanic systems.

Coexisting copper sulfides, bornite (Bn) and chalcopyrite (Ccp), with anhydrite (Anh), in PCD ore from Chile.
Methodology

The project will take a multidisciplinary approach, using laboratory experiments, field work, and geochemical modelling.

Geochemical modelling software, such as Geochemists Workbench, will be used to explore a variety of reactions involving SO\textsubscript{2}-bearing fluids and crustal rocks, including those containing metal-rich brines. Implications for ore-formation will be evaluated.

High-temperature and pressure laboratory experiments will be used to explore the three important aspects of the ore-forming process. The first is the extent to which magmatic fluids can become endowed with all of the requisite ingredients for ore formation, viz. metals, chloride and sulfur. This will be done using experiments on melt-fluid systems in cold-seal apparatus at pressures of 1 to 2 kbar. The second aspect concerns the behaviour of SO2-bearing fluids as they undergo decompression and reaction with host rocks at shallow levels. The third aspect is the role of mineralising fluids in driving hydrolytic alteration reactions in the rocks with which they interact. The second two sets of experiments will be conducted in hydrothermal apparatus.

Fieldwork will involve the study of mineralised rocks from PCDs, such as the one shown above, to compare the mineral textures and compositions to the experimental results. This aspect of the project will employ a variety of analytical techniques including electron microscopy, electron microprobe analysis and x-ray diffraction.

Timeline

**Year 1:** Literature survey and preparatory coursework. Geochemical calculations. Cold seal experiments.

**Years 2 and 3:** Hydrothermal experiments. Field work and sample analysis.

**Year 4:** Development of conceptual model and testing against natural examples of PCDs. Writing.

Training & Skills

This industry-funded project requires a wide and interdisciplinary skill set. The training will aim to fill gaps in knowledge and skills. For example, the student might take a graduate-level course in geochemical modelling and may follow other courses in materials science or Earth science as appropriate. Attendance at a summer school is expected, depending on availability.

The student will also learn through weekly project meetings with the supervisors. A key focus will be on scientific writing and illustration for publication.

Other courses on professional skills are available through the University. Attendance is encouraged.

The student will be a member of the Experimental Petrology research group which currently numbers approximately 18 staff, post-docs, DPhil students and visitors. Access and training will be provided for the departments wide array of experimental and analytical facilities, including all of those needed for this project.

References & Further Reading


Further Information

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