Resources for sustainable energy: ore formation by percolative reactive flow

Supervisory Team

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Key Words

igneous petrology, experimental petrology, mathematics, modelling, field work

This project is suitable for applicants with a training in igneous petrology, including field, laboratory, and theoretical skills. An interest in and capacity for thermodynamics is essential. Some training in applied mathematics and experimental petrology is expected.

Overview

The transition to Net Zero will present many challenges for the energy and mineral resources sectors. Business-as-usual mining and power generation are not options, and reduced consumption plus recycling will not be sufficient. New supplies of many metals will be needed to sustain the electrification of vehicles and to grow carbon-free energy generation. Many such metals are associated with large, layered intrusions, such as the giant Bushveld Intrusion in South Africa. But exploration is hindered by a lack of understanding of the fundamental mechanisms of ore formation from igneous bodies. This project aims to develop and test a new hypothesis for the accumulation of high-grade metal ores in igneous intrusions.

The dominant hypothesis for the formation of such ores is crystal settling from a solidifying batch of liquid magma. Yet this hypothesis struggles to address the widespread failure of geophysical surveys to identify modern liquid-filled magma batches large enough for such crystal–liquid processes to take place. Instead, most, if not all, igneous systems appear to operate as ‘mushy’ systems, rich in solid crystals with an intergranular melt phase. Because the melt is buoyant, it percolates through the crystal mush, transporting chemical components and reacting with solids en route. This process is called percolative reactive flow.

The testable hypothesis underlying this project is that percolative reactive flow is responsible for the formation of mineralised horizons in layered intrusions. Percolation of fluids, such as silicate melt, water or hypersaline brine, through a chemical potential gradient is a well-known process for producing monomineralic layers in metasomatic rocks. The same processes will apply in large, long-lived mush systems where there are vertical chemical potential gradients. For example, the figure shows how pure magnetite layers (a common feature of the Bushveld and a rich source of vanadium and titanium) might form at the interface of olivine- and orthopyroxene-rich anorthosites by the upwards movement of a fluid that works to eliminate chemical-potential gradients. By contrast, in the conventional interpretation these monomineralic layers are discrete injections of magnetite-saturated basaltic melt into a large magma chamber.

Chemical potential gradients

Fluid percolation through a crystal mush pile as a potential mineralisation process has not been previously analysed. In this project the student will explore the hypothesis of percolative reactive flow as an ore-forming process, define the circumstances when it is most likely to occur, and apply this new understanding to explore for new metals resources.

Methodology

The project will take a multidisciplinary approach, using laboratory experiments, field work, theoretical development and mathematical analysis (including numerical modelling).
High-temperature and pressure laboratory experiments will be used to test the hypothesis conveyed in the figure. Juxtaposing different, fluid-bearing rock types in a chemical potential gradient will be used to see if monomineralic layers form at the interface, how fast such layers grow, and how metals, such as V, Cr and Ti, segregate into these layers.

The field work will be conducted in South Africa, examining selected parts of the Bushveld Intrusion where monomineralic layers occur. Sampling of these layers and characterisation of their mineralogy and textures will provide an important test of the experimental and modelling results.

The modelling component will synthesise the laboratory and field work into a quantitative theoretical framework. This will be based on conservation laws with an empirical closure for chemical potentials in idealised systems with low degrees of freedom. The theory will be applied to experiments for validation and will then be extended to natural systems. Mismatch with natural rocks will motivate and constrain an elaboration of the theory to better capture the complex natural potentials. Scaling analysis, analytical solution, and numerical methods will all be deployed to explore the behaviour of the mathematical models.

**Timeline**

**Year 1:** Literature survey and preparatory coursework. Identification and design of relevant experiments. Field work and sample analysis.

**Years 2 and 3:** Completion of experiments. Derivation of idealised mathematical model and exploration of solutions. Field work.

**Year 4:** Further development of mathematical model to address complexity of natural systems. Writing.

**Training & Skills**

The 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 scientific computing, and may follow other courses in mathematics, 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.

**References & Further Reading**


**Further Information**

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