Durham University

GeoNetZero CDT
The Centre for Doctoral Training (CDT) in Geoscience and the Low Carbon Energy Transition

Understanding the controls on enrichment and mobilisation of critical metals from granite

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The UK transition to renewable energy relies on developing secure domestic pathways to source critical metals, including lithium as a key component of rechargeable batteries. Some low-enthalpy geothermal fluids, which can be used to generate renewable heat, contain high dissolved metal contents, including lithium. These fluids are associated with areas of high heat flow, and are underlain by large plutonic granite batholiths, including in northeast England (Manning et al. 2007; Figure 1) and in Cornwall (Edmunds et al. 1985). The potential to exploit both heat and metals found in these kinds of waters makes them an important exploration target. However, the primary source of the metals, and how they are mobilised into the geothermal system, is not well understood. For example, is the lithium present in geothermal fluids derived from sedimentary formation waters (e.g. Sanjuan et al. 2016) or a direct result of reaction with granite (e.g. Edmunds et al. 1985)? These open questions mean that the sustainability/ longevity of metal supply in geothermal fluids is poorly known, and hard to model.

Many evolved volcanic systems contain magmas with high concentrations of volatile species including halogens (F, Cl), boron and H_2O. These magmas also commonly show enrichment in trace metals, such as Li, Nb, Ta or Sn. The presence and composition of fluid at magmatic temperatures are major controls on the enrichment and depletion of these trace elements. During slow cooling and pluton formation, magmas crystallise within the crust and trace metals are incorporated into minerals crystallising at depth. Li is a trace component of many silicates but is particularly readily incorporated into micas and other hydrous minerals found in granites (s.l.), and commonly associated with halogens. This project will explore the processes of volatile and metal enrichment during granite crystallisation, and subsequent supply of those metals into later geothermal systems.

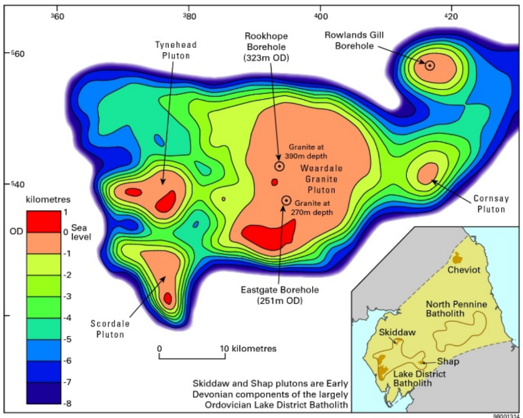

Figure 1: Surface of the Weardale granite and the North Pennine batholith. © BGS

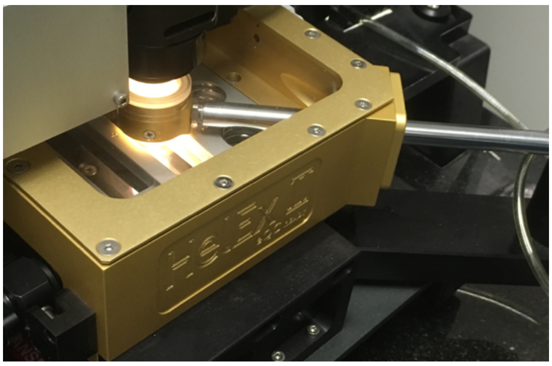

Figure 2: In situ microanalysis using laser ablation ICP-MS. © Madeleine Humphreys

The student will undertake *in situ*, spatially targeted micro-analysis (Figure 2) of trace elements and volatiles in key minerals from the granites, to assess and model trace metal enrichment relative to volatile evolution during different stages of magma crystallisation. Leaching/ reaction experiments at elevated pressures and temperatures (Figure 3) will be used to evaluate the reactivity of host rocks of differing mineralogy, and to quantify how metals are later extracted into circulating fluids.

Figure 3: Cold-seal pressure vessels will be used for high-P-T leaching experiments. © Martin Mangler

Using these datasets, together with structural models and published data on geothermal fluids, the student will evaluate the potential of granites to enrich critical metals, and develop models for the mobilisation and extraction of metals in granite-related systems. The student will then consider the implications for the potential longevity or sustainability of supply.

Outline of planned work for the project

Year 1: Fieldwork and sampling in Cornwall; petrographic examination of materials from geothermal boreholes (e.g. Eastgate, Rookhope) and other samples. Detailed *in situ* geochemical microanalysis of major elements/ halogens (EPMA) and trace elements (laser ablation ICP-MS) within minerals. Model primary enrichment and fractionation processes.

Year 2: Further *in situ* microanalysis of boron, lithium and halogens in hydrous minerals. Interpret data and create holistic geochemical model for high-T processes. Manuscript 1. Preliminary leaching experiments

Year 3: Leaching experiments covering range of T, P, t and fluid ligand chemistry. ICP-MS analysis of evolving fluids and petrographic and geochemical examination of solid residues. Manuscript 2.

Year 4: Integration with existing structural geology frameworks and development of models for metal mobilisation. Evaluate sustainability of supply. Manuscript 3. Thesis writing

Supervision, external partners and employability

The project involves both igneous petrology and water-rock interaction and is strongly linked to geothermal energy, and will provide a rounded training including laboratory techniques, scanning electron microscopy and multiple analytical microanalysis techniques. The project would suit a student with interests in igneous geochemistry and a willingness and aptitude for experimental laboratory studies, but also a keen interest in societally relevant research. The successful student will join the Durham Volcanology Group, Durham Geochemistry Centre and the Durham Energy Institute, as well as the GeoNetZero CDT training academy. The project also has links to Cornish Lithium and to Weardale Lithium. The student would be well placed to move into either industry or the academic sector following completion of their PhD.

Further information

For any informal enquiries about the project, please contact Dr Madeleine Humphreys, Durham University (madeleine.humphreys@durham.ac.uk).

References

Edmunds et al. (1985) *Chemical Geology* 49, 287-301
Manning et al. (2007) *Journal of the Geological Society, London* 164, 371-382
Sanjuan et al. (2016) *Chemical geology* 428, 27-47