Constraining the structural, geochemical and temporal evolution of a metamorphosed Cu-Zn-Au deposit in NW Scotland

Lead supervisor: Dr Steven Hollis, University of Edinburgh

Co-supervisors: Dr Taija Torvela, University of Leeds; Dr Ian Butler, University of Edinburgh, Dr Hannah Grant & Dr Kathryn Goodenough, British Geological Survey; Dr Gavin Berkenheger, Galantas Gold

Project Highlights:

- Become upskilled in several state-of-the-art analytical methods to constrain the structural, geochemical and temporal evolution of a strongly deformed VMS deposit within its broader regional tectono-magmatic setting.
- Work in close collaboration with an exploration company (Galantas Gold), and aid in the discovery of additional lenses of mineralization.
- Development of a wide range of skillsets relevant to academic, industry and governmental career routes through both UK-wide and international collaboration.

Overview:

The global green energy transition will require significant amounts of metals for the development of renewable technologies. This includes both traditionally mined base and precious metals, and a number of critical metals whose supply is currently dominated by a handful of countries. Though predominantly mined for Cu-Zn-Pb-Ag-Au, volcanogenic massive sulfide (VMS) deposits can be enriched in a number of critical metals (e.g. Co, In, Bi, Sn, Te; Galley et al. 2007).

Hydrothermal alteration assemblages surrounding VMS deposits are relatively simple, and well-established mineralogical, geochemical and isotopic halos provide useful tools for exploration (Hollis et al. 2019, 2021). However, when preserved in high-grade metamorphic terranes, these alteration assemblages are overprinted and obscured (Dusel-Bacon, 2012). Furthermore, sulfides become recrystallized and metals (particularly Au) are often remobilised. Only 11% of VMS discoveries have occurred in host sequence metamorphosed to amphibolite conditions, and 0.5% in granulite facies rocks. There is significant room for new discoveries both within the UK and globally in these terranes (Deady et al. 2023).

This research project will focus on VMS exploration in NW Scotland near Gairloch, where a Besshi-type VMS deposit (Kerry Road) has been identified, along with over a dozen smaller occurrences in the regional stratigraphy (Williams et al. 1985; Jones et al. 1987). Massive sulfide mineralization is hosted in amphibolite facies mafic-siliciclastic units of the c. 2.0 Ga Loch Maree Group (Drummond et al. 2020). This PhD aims to constrain the structural, geochemical, and temporal evolution of the Kerry Road VMS deposit and surrounding mineral occurrences within a broader tectono-magmatic framework. This project will directly aid exploration efforts for massive sulfides, help constrain the nature of associated high-grade Au mineralization, and develop relevant exploration tools for similar deposits in the UK and globally.

This project will create a number of complementary 2D and 3D data sets to further understand mineralization within the Loch Maree Group. Optical microscopy, SEM, EPMA, µCT volumes and ToF maps will be integrated and explored using correlative microscopy methods. Mineralization processes will be investigated across a range of scales from regional outcrop mapping and deposit-scale 3D modelling, through to SEM and µCT scale.

Figure 1: a. Regional exposure of the Loch Maree Group. b. Outcropping gossanous massive sulfide. c. Tightly folded schistose footwall rocks. d. Massive sulfide mineralization in drill core from Kerry Road.

Key research questions:

This project aims to answer the following key research questions:

1) How has regional deformation affected the geometry of the Kerry Road VMS deposit and nature of massive sulfide mineralization?

2) Are intercepts of high-grade gold due to local remobilization from massive sulfides, or later regional metamorphic fluids?

3) Can robust alteration halos be established at Kerry Road using chlorite, white mica, amphibole and/or garnet, and can these be used to find additional ore lenses?

4) How can our understanding of Zn-Cu-Au mineralization in the Loch Maree Group, inform VMS exploration globally in highly metamorphosed terranes?

Mineralisation and associated metamorphosed alteration assemblages will be established through detailed core logging, field mapping (for lithology, alteration and structural evolution), and optical microscopy. A 3D model of the ore body will be produced using software package Leapfrog. Sulfide mineralogy and textures will be characterised by reflected light petrography, Scanning Electron Microscopy (SEM) and µCT at the University of Edinburgh, and EBSD analysis with Dr Taija Torvela at Leeds. The SEM at Leeds also has the capability to conduct elemental mapping via time-of-flight mass-spectrometer. Sulfide chemistry will be investigated by using an Electron Microprobe (EMPA) at the University of Edinburgh, and through LA-ICPMS mapping at Trinity College Dublin (Ireland) with Dr Sean McClenaghan. Alteration halos will be characterised through a combination of whole

rock geochemistry, and EMPA analysis of key mineral phases (e.g. garnet, amphibole, chlorite and white mica; Hollis et al. 2021) at the University of Edinburgh. The age of mineralization and regional metamorphism will be constrained through Re-Os (sulfide) and Lu-Hf (garnet) geochronology.

Possible timeline:

Year 1: Initial sample collection, field mapping and core logging. 3D modelling of the Kerry Road VMS deposit. Petrographic descriptions of sulfide assemblages and SEM analysis.

Year 2: Whole rock geochemical analysis. EBSD and EMPA analysis of selected sulfide bearing samples. EMPA analysis of silicate minerals. 3 month industry placement with Galantas Gold.

Year 3: LA-ICPMS and S isotope analysis of sulfide phases. Re-Os and Lu-Hf garnet geochronology. Thesis write up.

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.

In addition to the training within TARGET, the project provides specialist training in: (i) state-of-the-art microanalytical, geochemical and geochronological techniques; (ii) textural-structural and mineralogical analysis and field work; and (iii) industry-standard exploration, data management, and software skills. The PhD is equally suited to academia or industry careers. You will be able present at both national and international, academic or industry facing conferences according to your career trajectory.

Partners and collaboration (including CASE):

The main supervisor Dr Steven Hollis (Edinburgh) is an expert in VMS systems, particularly the application of alteration mineralogy, whole rock geochemistry and mineral-chemistry as exploration tools. Dr Taija Torvela (Leeds) provides expertise in structural geology and textural/paragenetic analysis of mineral assemblages. Additional TARGET supervision from the British Geological Survey is provided by Dr Hannah Grant (an ECR expert on modern and ancient seafloor hydrothermal systems) and Kathryn Goodenough (an expert on Archean mineral systems). Dr Ian Butler developed Edinburgh's µCT facility, and has extensive research experience on both hydrothermal and magmatic mineral systems.

CASE partner Galantas Gold will provide sample materials (drill core), geochemical datasets, local knowledge and a 3-month placement in year 2.

Requirements: The successful candidate will have at least a BSc with a high 2:1 or a 1st from a Earth Sciences, Geology or similar programme; an MSc/MGeol qualification or relevant industry experience is advantageous. Excellent time management, critical thinking and analytical skills, ability to collate, analyse and interpret multiple different datasets, and the ability to clearly communicate results are essential.

Further reading:

Deady et al. (2023). 'Potential for Critical Raw Material Prospectivity in the UK'. British Geological Survey CR/23/024, 57 pp.

Drummond, D.A. et al. (2020). 'Petrogenesis and geochemical halos of the amphibolite facies, Lower Proterozoic, Kerry Road volcanogenic massife sulfide deposit, Loch Maree Group, Gariloch, NW Scotland'. Ore Geology Reviews, 124, pp. 103623.

Dussel-Bacon, C. (2012). 'Petrology of metamorphic rocks associated with volcanogenic massive sulfide deposits' USGS, 17, 10p.

Galley, A.G., Hannington, M.D. and Jonasson, I.R. (2007). 'Volcanogenic massive sulphide deposits'. In: Goodfellow, W.D. (Ed.), A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods. Geological Association of Canada, Mineral Deposits Division, Special Publication, vol. 5. pp. 141–161.

Hollis, S.P. et al. (2019) 'Targeting VHMS mineralization at Erayinia in the Eastern Goldfields Superterrane using lithogeochemistry, soil chemistry and HyLogger data'. Journal of Geochemical Exploration, 207, 106379. https://doi.org/10.1016/j.gexplo.2019.106379

Hollis, S.P. et al. (2021) 'Lithogeochemical and Hyperspectral Halos to Ag-Zn-Au Mineralization at Nimbus in the Eastern Goldfields Superterrane, Western Australia.' Minerals, 11, pp. 254. https://doi.org/10.3390/min11030254

Jones, E. et al. (1987). 'Lower Proterozoc stratiform sulphide deposits in Loch Maree Group, Gairloch Northwest Scotland'. Inst. Min. Metal., 96, p.128-140.

Williams, P. et al. (1985). 'Petrology and deformation of metamorphosed volcanic-exhalative sediments in the Gairloch Schist Belt, NW Scotland.' Mineralium Deposita, 20, pp. 302-330.

Further details:

Contact Steven.Hollis@ed.ac.uk for further project particulars.

Please visit https://target.le.ac.uk/ for additional details on how to apply.