IMPERIAL

Source-to-Sink Analysis of Critical Metal Mineralisation

Supervisors

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Research Group

Solid Earth–Fluid Earth Interactions (SoEFEI) Group (https://freddrichards.github.io/team/)

Project Summary

Decarbonising the global economy to reduce the rate of anthropogenically induced climate change will involve the deployment of a wide range of clean energy technologies. Although these technologies significantly reduce greenhouse gas emissions, they are significantly more material-intensive than their hydrocarbon-fuelled counterparts, resulting in unprecedented demand for metals. With global energy requirements only increasing alongside the need to cut emissions, this burgeoning demand risks outstripping the supply of certain metals, leading many governments to designate them as ‘critical’.

Inherent limitations on the ability of recycling to address potential shortfalls in critical metal supply mean there is a growing need for exploration and production of new deposits. However, despite rising exploration expenditure, mineral deposit discovery rates have slowed over the past decade (Schodde, 2017), highlighting the need for novel exploration approaches that employ a more holistic understanding of the geological settings and processes necessary to facilitate large-scale deposit formation. Key to these new techniques is reliable data on the thermochemical and geodynamic evolution of the lithosphere which controls the timing, magnitude, and style of mineralisation. While geophysical methods provide critical insight into present-day lithospheric architecture, geochemical analysis is needed to unravel the time evolution of mineral systems, to reduce the non-uniqueness of thermochemical structure inferred from geophysical data, and to constrain the processes that enrich source regions, generate fluids capable of transporting metals, and control eventual ore deposit emplacement (Hagemann et al., 2016, *OGR*).

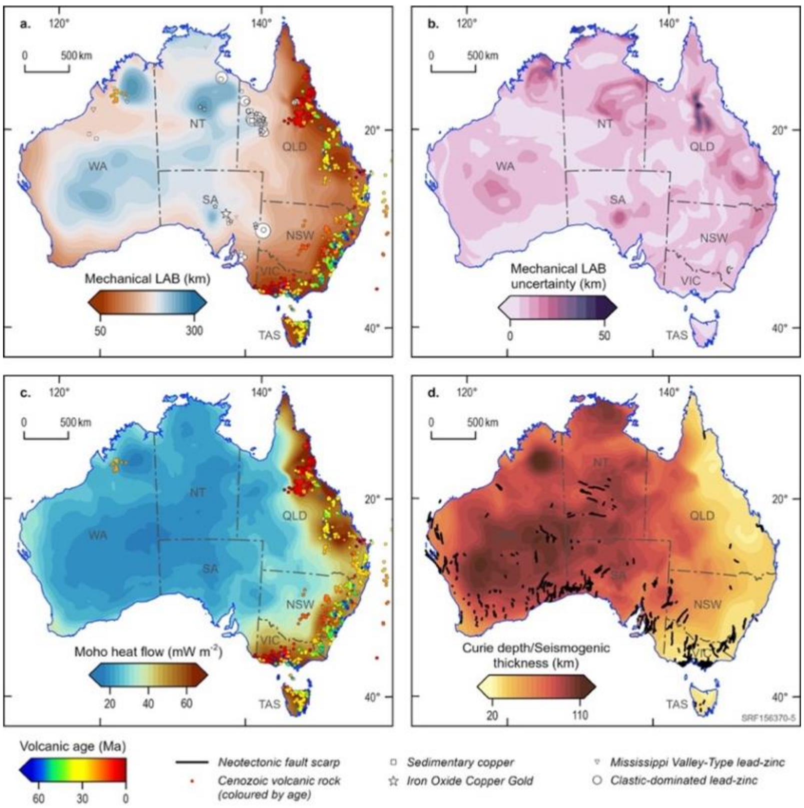

Figure 1: Spatial correlation of inferred Australian thermomechanical structure with locations of mineral deposits and key volcanotectonic features. (a) & (b) Mechanical LAB depth (i.e., depth to 1175 °C isotherm) and associated uncertainty. (c) Moho heat flow. (d) Curie depth (i.e., depth to 600°C isotherm). Redrawn from Hoggard et al., 2024.

Research Context and Objectives

This project will take advantage of recent breakthroughs in geochemistry, geophysics, and geodynamics, alongside fieldwork in the Western US, to holistically reconstruct mineral system evolution. First, thermodynamic databases are now available for the full range of plausible mantle and crustal compositions, as are the efficient computational models needed to rapidly predict their physical properties as a function of pressure and temperature (Weller et al., 2024, *J. Petrol.*). Secondly, the rapid growth of continent-scale high-resolution magnetotelluric, seismic, and potential field datasets (e.g., AusArray and AusLAMP, in Australia), provides unprecedented constraint on the subsurface structure of mineral systems. Thirdly, new compilations of xenolith chemistry enable independent verification of geophysically inferred thermochemical structure (Sudholz & Copley, 2025, *GRL*). Finally, we can now predict the coupled dynamics of lithospheric deformation, melt production, and surface processes using advanced geodynamic software packages (e.g., ASPECT), enabling macroscale simulation of entire mineral systems from mantle or crustal sources to near-surface sinks.

This will involve:

1) Integrating novel thermodynamic databases into in-house multiobservable inverse modelling software to probabilistically quantify thermochemical structure of Australian and North American continental crust and lithospheric mantle.
2) Combining inversion outputs and surface geological data with machine learning approaches to establish geochemical, geophysical, and structural ‘fingerprints’ that are diagnostic of key mineral deposit types in these regions (e.g., Cu porphyry, IOCG, and clastic-dominated Pb-Zn).
3) Producing geodynamic models that can explain the development of these signatures, providing new constraint on how their associated mineral systems have evolved through time.

N.B. Fieldwork in the Laramide copper porphyry belt will be undertaken In late 2027 to expand the database of surface geological data that will be used to establish mineral system ‘fingerprints’ and to validate geodynamic models.

The core aim of this work is to move from a descriptive to a mechanistic understanding of critical mineral systems, improving the applicability of this framework to mineral exploration, while also providing new geochemical and geophysical tools to improve exploration success in frontier regions.

Further reading:

Hoggard, M., Hazzard, J., Sudholz, Z., Richards, F., Duvernay, T., Austermann, J., Jaques, A.L., Yaxley, G., Czarnota, K., & Haynes, M. (2024). Thermomechanical models of the Australian plate, *Exploring for the Future: Extended Abstracts, Geoscience Australia*, Canberra.

Who are we looking for?

The successful applicant will be an Earth scientist with prior computational experience and an interest in conducting research that cuts across the disciplinary boundaries of economic geology, geochemistry, geophysics, and geodynamics. Some field experience will be essential.

The candidate will have the chance to visit and collaborate with project partners at Australian National University, Geoscience Australia, and University of Nevada, Las Vegas. They will be supported in raising their academic profile through annual attendance of national and international conferences, and will be joining a vibrant and supportive group, where training is carefully tailored to individual needs and goals.