Integrated Geochemical, Geophysical, and Geodynamic Source-to-Sink Analysis of Critical Metal Mineralisation

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Project Highlights:

- Integrating novel geochemical, geophysical and geodynamic techniques to obtain holistic understanding of metallogenesis in various tectonic settings.
- Developing unified models for the formation of key mineral deposits types (e.g., Cu porphyry, IOCG, and clastic-dominated Zn-Pb).
- Opportunity to work with international team and conduct fieldwork in Western US.

Overview:

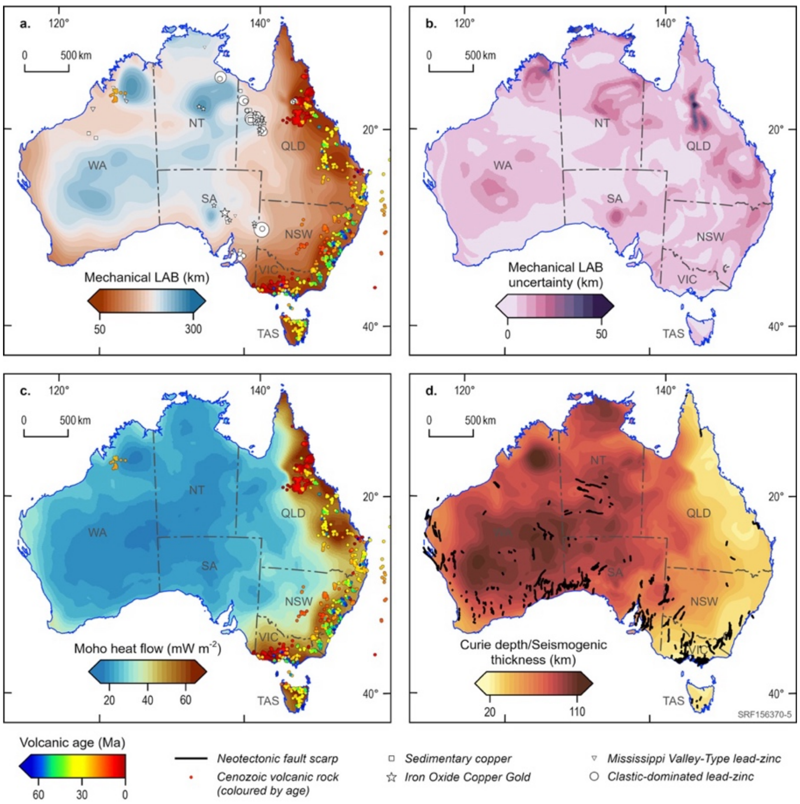

Figure 1: Spatial correlation of inferred Australian thermomechanical structure with locations of mineral deposits and key volcanotectonic features. (a) & (b) Mechanical LAB depth (i.e., depth to 1175 °C isotherm) and associated uncertainty. (c) Moho heat flow. (d) Curie depth (i.e., depth to 600°C isotherm).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

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 geodynamic and thermochemical evolution of the lithosphere which ultimately 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 deposit emplacement (Hagemann et al., 2016).

Methodology:

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). 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, 2024). 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.

Possible Timeline

Year 1: Integrate novel thermodynamic databases into in-house multiobservable inversions to probabilistically quantify thermochemical structure of Australian and North American continental crust and lithospheric mantle.

Year 2: Combine 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).

Year 3: Produce 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 at the end of Year 1 to expand database of surface geological data that will be used to establish ‘fingerprints’ (Year 2) and validate geodynamic models (Year 3).

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.

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.

Additional training will be given in geological fieldwork skills, scientific computing, geodynamic modelling, thermodynamic modelling, and machine learning for science.

Partners and collaboration (including CASE):

The successful applicant will collaborate closely with project partners throughout the project to validate the outputs of thermochemical inversions and geodynamic simulations using independent xenolith and melt inclusion constraints. At the end of Year 1, fieldwork in the Laramide porphyry copper belt will be conducted alongside Dr Tom Lamont at the University of Nevada Las Vegas to establish additional structural and surface geological constraints for deposit fingerprinting and geodynamic modelling work in Years 2 and 3. Dr. Lamont will be a core collaborator throughout these last two years.

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.

Sudholz, Z. J., and Alexander Copley (2025). Xenolith constraints on the mantle potential temperature and thickness of cratonic roots through time. *Geophysical Research Letters*, **52**, e2024GL112851.

Weller, O. M., Holland, T. J., Soderman, C. R., Green, E. C., Powell, R., Beard, C. D., & Riel, N. (2024). New thermodynamic models for anhydrous alkaline-silicate magmatic systems. *Journal of Petrology*, **65**, egae098.

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply. Contact f.richards19@imperial.ac.uk for more information on the project.