From Source To Sink: Experimental and modelling constraints on copper mobilisation and deposition in sedimentary basins

Lead Supervisor: Prof. Matthew Jackson, Imperial College

Co-supervisors: Prof. David Holwell, University of Leicester, Prof. Jamie Wilkinson, Imperial College

Project Highlights:

- Experimental evidence for controls on metal release from red-bed sandstones and insights into source rock fertility in different basins
- Testing the importance of secular variability of brine chemistry on metal mobilisation
- Identification of critical basin-scale and local controls on copper transport and deposition from numerical models
- Development of multivariate and ML tools for discrimination of fertile Cu basins

Overview:

Sediment-hosted copper deposits account for approximately 23% of the world's discovered copper and typically host higher-grade ores than other types of hydrothermal deposits. Their global economic significance has stimulated over a century of research devoted to understanding their geological setting and controls of formation. This has demonstrated that most deposits were formed by leaching of copper and other metals from source rocks; transport of the metals in oxidising, chloride-rich brines as they flow through porous, permeable rocks or along faults; and precipitation of copper as sulphide minerals under reducing conditions. Many deposits were formed at redox boundaries between permeable, oxidised continental red-beds and reduced, lacustrine or marine sediments, although the discovery of major deposits in reduced units of the glaciogenic Grand Conglomerat in the Central African Copper Belt has expanded the range of suitable host lithologies.

Although this general model for copper ore formation is broadly accepted, there are still major uncertainties and controversies concerning the timing of mineralisation, the source rock(s) from which copper and other metals are extracted, the efficiency with which brines can leach copper from the proposed source rock(s), the composition of the brines responsible for metal leaching and transport, the temperatures and depths at which metals are leached and deposited, the forces that drive brine flow, and whether mineralisation occurs during a single pass of metal enriched brine, or during circulation of brine with multiple cycles of metal enrichment and mineral deposition. These knowledge gaps severely impact our ability to develop predictive models for copper localisation in basin systems and, more widely, the controls of basin metallogenic potential.

The aim of this project is to constrain mechanisms of extraction, transport and deposition of copper using laboratory experiments combined with advanced, basin-scale numerical models built with georealistic geometries. The laboratory experiments will use an established methodology to: (1) use aqua regia leaching to evaluate potential fertility of red bed sequences from different basins worldwide and from different parts of the Katangan Basin in the Central African Copper Belt; and (2) determine the efficiency with which copper and other metals can be leached from potential source rocks by simulated natural brines (incorporating secular variability in brine compositions) at relevant conditions of temperature, pressure and oxidation state [1,2]. These data will be used in an advanced numerical modelling tool [3,4] to explore: (i) the conditions and processes that lead to mobilisation and transport of copper in brines, including the control of heterogeneous stratigraphic architecture in terms of distribution of carbonate-bearing and reduced facies; (ii) the implications of potential interactions of such brines with petroleum during its generation and migration; and (iii) how copper deposition can be optimised in such flow regimes in terms of structural geometries and stratigraphic architecture. The modelling will focus on potential controls on localisation of copper mineralisation in the Central African Copper Belt using appropriate, camp-scale, basin geometries.

The project builds on methods and results developed in the NERC-funded CuBES project (Copper Basins Exploration Science; see Fig. 1), minimizing the need for further method development and allowing rapid delivery of new results and insight. The project is designed to address fundamental controls of sediment-hosted copper deposit genesis, including secular variations in seawater-derived brine chemistry and paleoclimatic and geodynamic impacts on fertile basin fill and architectures. This will have direct implications for better defining the exploration search space for new deposits of this type.

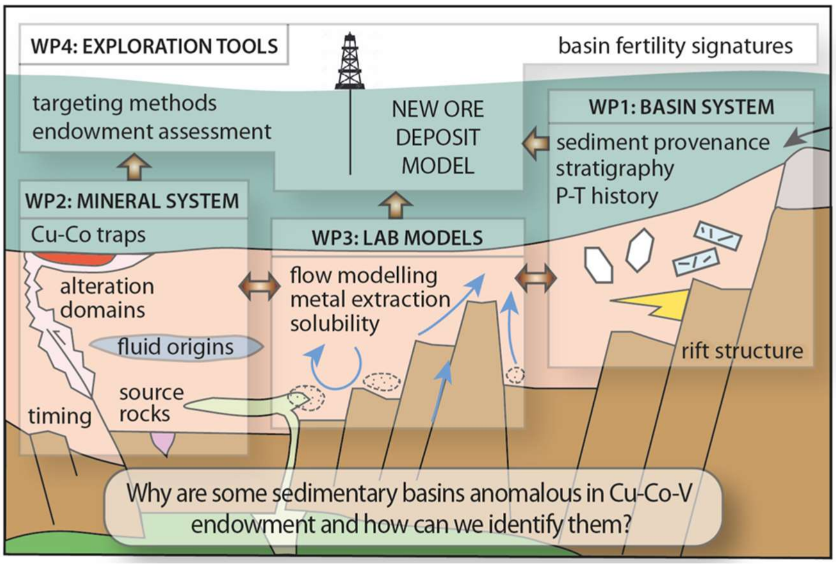

Figure 1: Research schematic of the completed NERC CuBES project; the PhD research will build on ideas developed across the work packages (WP) completed in CuBES.

Key research questions:

This project aims to answer the following key research questions:

1) How does extractability of Cu and other metals from red-beds vary between basins and what are the mineralogical controls?

2) Can a discrimination tool be developed based on simple aqua regia leaching data to assess basins for potential mineralisation endowment?

3) Do secular variations in brine major element chemistry influence mobility of metals from red-beds?

4) What are the critical basin-scale conditions and permeability and trap geometries that lead to the formation of high-grade Cu mineralisation?

Methodology:

Samples will be acquired from multiple key basins through collaborative work, existing collections and targeted field campaigns. More detailed sampling will be done in the Katangan Basin of the central African Copper belt, supported by the CASE partner(s), to constrain lateral and stratigraphic variability in potential source rock petrology and metal availability. Samples will be analysed for their bulk rock multielement geochemistry and characterised mineralogically using quantitative automated-SEM to constrain provenance mineralogy and any diagenetic/metamorphic overprints before testing metal mobility using:(1) low-temperature aqua regia leaching (large number of samples); and (2) moderatetemperature brine leaching (subset of the samples), with leachate solutions analysed by ICP-AES and ICP-MS techniques. Numerical modelling using existing finite element code (IC-FERST) will be carried out using broad basin scale and local-scale geometries to test different scenarios for focusing fluid flow and metal deposition, informed by metal extraction results derived from the experimental programme. Aqua regia leachate data across and within individual basins will be used to explore potential basin fertility discrimination signals using multivariate statistics and AI methods and derive applicable assessment tools.

Possible timeline:

Year 1: Literature review, development of sediment-hosted Cu geology understanding, sample acquisition by development of international collaborations and an initial field campaign. Put first set of samples through the preparation, petrographic and analytical workflow, including initial aqua regia experiments. Report on initial petrographic and experimental results at conference 1.

Year 2: Second field campaign to widen sample set, with a focus on the Central African Copper Belt. Put second set of samples through the preparation, petrographic and analytical workflow, with a first subset of the samples being leached using synthetic brines. Complete aqua regia experiments. Design and run first set of larger-scale numerical flow models. Report on expanded results at conference 2.

Year 3: Explore inter- and intra-basin aqua regia datasets and evaluate statistical and AI models for discrimination of basin fertility. Complete the brine leaching experiments. Expand the numerical models to include a variety of camp-scale geological scenarios, utilising metal extraction data from the experimental studies. Report on main findings of research at conference 3. Plan thesis structure and begin 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.

At Imperial, the student will receive training in lab safety, sample preparation, experimental and numerical modelling methods (Jackson). Courses in transferable and various technical skills including use of software and coding, and public engagement opportunities, will be available. At Imperial College, instruction in sediment-hosted Cu geology, geochemical interpretation using ioGAS and technical training in machine learning methods will be provided (Wilkinson and colleagues). Training in fieldwork and sediment-hosted Cu geology will be done by Holwell and Wilkinson, potential attendance on field training courses (e.g. SEG), and by CASE partner technical staff. Training in mineral analysis will be mainly completed at Leicester University using automated SEM supervised by Holwell and the lab support team.

Partners and collaboration (including CASE):

The student will be based jointly at Imperial College and Leicester University and will work with the CASE partner(s) as appropriate. Demonstrating opportunities for undergraduate classes at Imperial