Quantifying the role of fault-related shear stress in the genesis of critical mineral deposits

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Project Highlights:

- Addressing a fundamental science question with a direct application to the Energy transition;
- Integrating field work, novel laboratory rock deformation experiments, microstructural and microchemical analysis and numerical modelling;
- Future career pathways in academic rock mechanics and ore geology or applied mining geology of critical mineral deposits.

Overview:

Major deposits of critical minerals and metals occur in close proximity to faults. Examples include copper and cobalt (Cu, Co), lead-zinc (Pb, Zn) with associated gallium and indium, and lithium (Rowe & Burley, 1997; Wu et al., 2024). This mineralisation can entirely post-date active faulting, with mineral-rich brines infiltrating newly created pore space in damage zones, or trapping against tectonically-induced permeability barriers. But some deposits may have a much closer genetic link with brittle shear deformation. Rock deformation experiments on sandstones have shown spikes in the concentration of Si and other major elements in the aqueous pore fluid just before brittle shear failure (Ngwenya et al., 2000), and the mixing of these fluids with metal-rich brines may trigger ore deposition. More recently, it has been shown that the piezoelectric behaviour of quartz can aid the deposition of gold nuggets (Voisey et al., 2024). These findings are consistent with a role for elevated shear stress during brittle faulting in the genesis of critical mineral ore deposits. This project addresses a fundamental scientific question with a direct application to critical minerals for the energy transition: What role does faulting – increased shear stress – play in the accumulation of critical mineral deposits?

In this project, the student will aim to deliver:

- Detailed multiscale maps of 3 fault zones and mineralisation in selected mineral deposits in sandstone, limestone and granite;
- Laboratory experiments designed to explore the role of fault-related shear stress on pore fluid chemistry and mineralisation in 3 sets of samples of sandstone, limestone and granite;
- Microstructural and microchemical analysis of ore mineral textures in relation to deformation fabrics in natural and laboratory fault zones;
- A quantitative understanding of the relationship between brittle deformation and the occurrence of critical minerals.

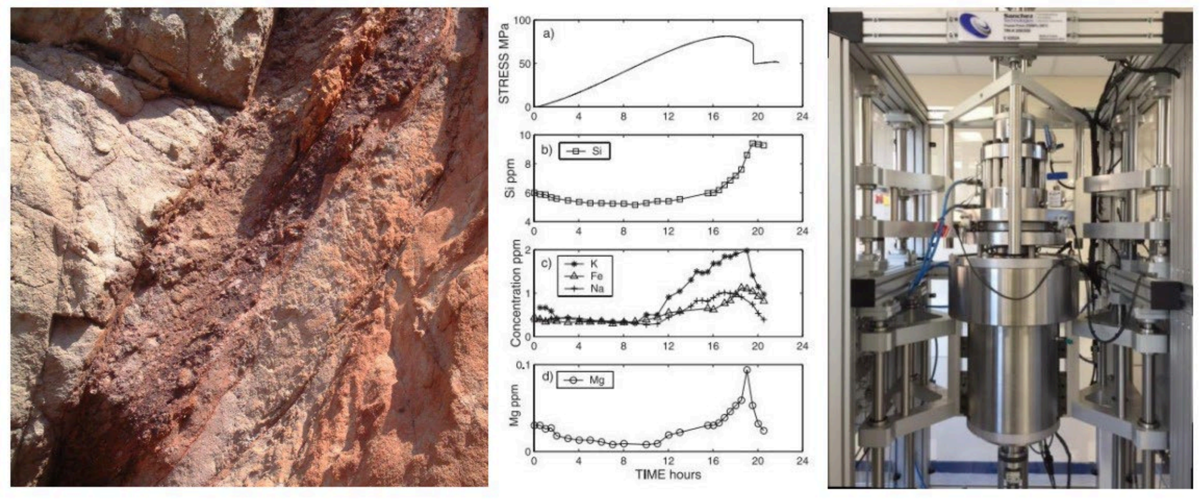

Figure 1: A natural fault zone in sandstone (left) showing the products of intense shearing along the fault plane; the chemical signature of increasing shear stress in laboratory deformed sandstone (centre); the Sanchez conventional triaxial apparatus at the University of Leeds (right).

Methodology:

Mineralised fault zones in sandstone, limestone and granite (Alderley Edge, South Pennine Orefield and Cornwall, respectively; all UK) will be sampled with all necessary permissions following detailed structural mapping. Experiments will be conducted at Leeds using a conventional triaxial rock deformation apparatus capable of temperatures to 200°C, and at UCL using their true triaxial apparatus. Data collected will include stress-strain, strength, pore volume change and permeability, and pore fluid chemistry for major elements, all as a function of changing shear stress. Microstructural and microchemical analyses will be conducted on pre- and post-test samples at the Leeds Electron Microscopy and Spectroscopy Centre (LEMAS, Bragg Centre for Materials Research). SEM images will be collected in SE, BSE, EBSD and EDS modes to map changes in chemistry, porosity, microcracking and plastic deformation. Numerical modelling will explore the consequences of coupled brittle shear deformation and fluid chemical change as a function of shear stress.

Possible Timeline

Year 1: Field mapping, structural characterisation and systematic sampling (with all necessary prior permissions); initial pilot rock deformation tests to gain experience with the apparatus and establish a baseline for further tests; presentation at a national conference.

Year 2: Rock deformation tests at various strain rates, confining pressures and temperatures on selected samples of sandstone, limestone and granite; microstructural and microchemical analyses of pre- and post-mortem thin section samples of the same rocks, including fluid inclusion analyses; preliminary data analysis, model building and testing; presentation at an internation conference.

Year 3: Further data analysis and model refinement, with any extra rock deformation tests deemed necessary to address specific issues arising; writing up and manuscript preparation.

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.

Training will be given in field-based structural geology, experimental rock physics, microstructural and microchemical analysis and numerical modelling. Field training will include detailed mapping, digital photogrammetry, scanline surveys and oriented sample collection (with permissions). Laboratory training will include sample preparation, machine calibration, rock property testing and experimental data analysis, and microstructural and microchemical analyses on the SEM. Numerical modelling will foster an open source/open data approach to software development and publication. The student will be encouraged to present their work at national and international conferences and given the opportunity and support to submit publications to international peer-reviewed journals.

Partners and collaboration (including CASE):

The project will be based at the School of Earth & Environment (SEE) at Leeds supervised by Healy and Piazolo, with short stays at UCL supervised by McFall and Mitchell. Experiments on the newly commissioned true triaxial apparatus at UCL with Co-I Mitchell will explore the role of the intermediate principal stress in promoting dissolution along fault planes (not possible in conventional axisymmetric triaxial apparatus). Fluid inclusion analyses at UCL with Co-I McFall will determine the temperatures of fault rock deformation and natural ore mineral deposition at the selected field sites, and inform the experimental programme at Leeds.

Further reading:

Ngwenya, B.T., Elphick, S.C., Main, I.G. and Shimmield, G.B., 2000. Experimental constraints on the diagenetic self-sealing capacity of faults in high porosity rocks. Earth and Planetary Science Letters, 183(1-2), pp.187-199.

Rowe, J. and Burley, S.D., 1997. Faulting and porosity modification in the Sherwood Sandstone at Alderley Edge, northeastern Cheshire: an exhumed example of fault-related diagenesis. Geological Society, London, Special Publications, 124(1), pp.325-352.

Voisey, C.R., Hunter, N.J., Tomkins, A.G., Brugger, J., Liu, W., Liu, Y. and Luzin, V., 2024. Gold nugget formation from earthquake-induced piezoelectricity in quartz. Nature Geoscience, pp.1-6.

Wu, J., Han, R., Zhang, Y., Sun, B., Li, W., Li, D., Cao, Y. and Cen, C., 2024. The fault–fold structure ore control mechanism of hydrothermal deposits——A case study of the Maoping super-large rich-Ge lead–zinc deposit in northeastern Yunnan, China. Ore Geology Reviews, p.106039.

Further details:

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

Further information on the project is available from Professor Dave Healy d.healy@leeds.ac.uk and from [Geosolutions Leeds](#).