The emergence of responsible small-scale mining for critical minerals

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Project Highlights:

- A technocultural approach towards sustainability, combining mineral matters and human matters
- The liberation and concentration of tin from ore deposits at small-scale mines using intermediate technologies
- Co-creation of mining models for socioenvironmental justice, based on shared knowledge and diffusion of innovation

Overview:

Minerals are described as critical when there is a risk of supply not meeting demand, and supplies may be threatened where production is from few mines, or at few processing centres, where disruptions (i.e. environmental, social, geopolitical) could occur. A mechanism to create more resilient supply chains is by diversification of resources. This can be viewed from a geological perspective only, or from an organisational and strategy development perspective. The proposed research combines these in a technocultural methodology of social earth science, to investigate how alternative scales of mining can contribute to production from critical mineral ore bodies, and how small-scale miners can be supported in understanding their ore bodies and processing routes.

Artisanal (ASM) and technological (SSM) small-scale mining collectively employ over 40 million people worldwide and are more effective in equitably distributing the benefits of mining than large scale mining. While SSM is less efficient than large-scale mining, it can be formalized and regulated to improve environmental performance and it can provide a route out of poverty-associated ASM (Johnson et al., 2024, 2025). ASM and SSM production has been dominated by gold but critical minerals have also been produced, and this will accelerate for commodities with consistently high prices and where communities turn to critical mineral mining for meaningful rural work. Ore bodies are 'complicated' where tin, tungsten, tantalum and gold fuel conflict. This project focusses on the lessons that can be learned in the safe operating space of the tin production landscape of Zambia, and how these lessons can be applied more widely.

This project will place investigations in the geological context of tin ore bodies, the suitability of intermediate technologies that are available for small-scale critical minerals separation and processing, and the societal/regulatory landscape. It will consider how the knowledge of geometallurgical and environmental approaches is shared and how sustainability agendas are fostered. It will research how co-creation models for SSM have been developed, where vulnerabilities

lie and how they will need to be nurtured to ensure the long-term viability of operations and positive net outcomes from SSM.

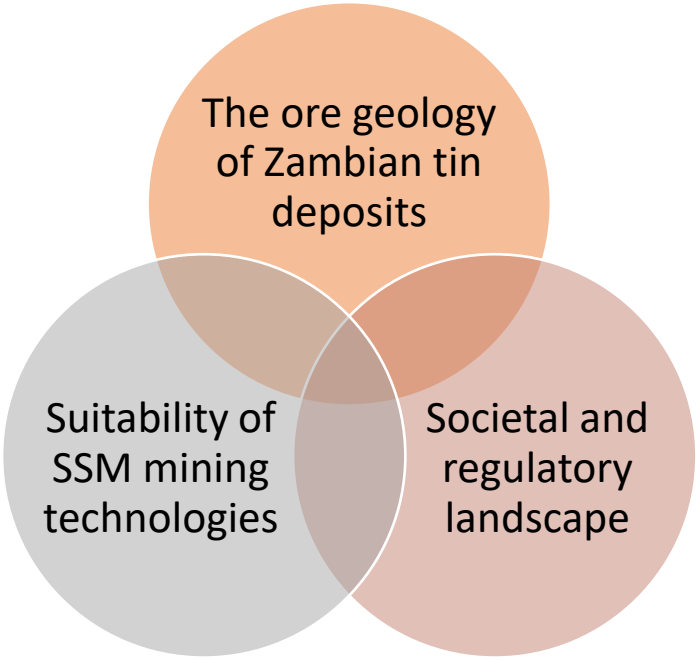

Figure 1: Venn diagram of the pillars underpinning the co-creation models explored by the student. SSM: small-scale technological mining.

Methodology:

The theoretical approach is technocultural - working at the interface between minerals matters and human matters – to understand what constitutes strong sustainability. The student will research:

1. geological groundings of socioenvironmental justice by SSM,
2. geometallurgical underpinnings of how to engineer sustainable SSM mineral development,
3. knowledge co-production and mining-community co-creation of SSM mining plans.

The research will involve field campaigns in the primary case study area in Zambia. A sampling campaign will be used to yield samples for characterisation and liberation studies (minerals and rock particle analysis), to support a survey of the suitability of available intermediate technology equipment that does not involve excessive cost. The fit to purpose of the available equipment (e.g. gravity-based technologies; Moore et al., 2021) to the local socio-environmental conditions will be examined through participatory approaches, involving semi-structured interviews and field observations, and analysis of formalization mechanisms.

Possible Timeline

Year 1: Ethics for responsible research and innovation in a development context and literature review of environmental justice in resource extraction contexts. Fieldwork in Zambia to involve orientation, field survey and sample collection. Survey of regulatory and stakeholder frameworks to facilitate planning of semi-structured interviews.

Year 2: Laboratory analysis of samples and pilot liberation studies, to be augmented by further sampling, if necessary, during second field campaign, which will have a focus on semi-structured

interviews. Refined liberation investigation and examination of fit-to-purpose of low-cost intermediate technologies. Pilot thematic analysis of qualitative (i.e. stakeholder-generated) data.

Year 3: Final field visit if necessary for follow up semi-structured interviews. Full thematic analysis and decoding. Contextualisation of qualitative (human matters) data outputs using the quantitative (mineral matters) data, and vice versa to understand how co-creation models might be enhanced and made fit-for-purpose for SSM.

The student will meet with the primary supervisory team once per week to discuss progress and receive training and guidance, or with the CASE supervisor while on fieldwork with remote communications/check-ins with the primary supervisory team. They will meet with secondary supervisors every 3 months, if remote connections allow. The timeline remains flexible, particularly in relation to the duration and frequency of field visits. The students will use the opportunity of presentation at conferences to maintain their progress, presenting at at-least 2 national and 1 international conference.

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.

No applicant is expected to have all the transdisciplinary skills to undertake this project, so the supervisory team will provide training in any skills gap areas, be they geological and mineralogical, geometallurgical and/or social science. Regardless of background training, training will be provided in advances techniques: minerals analysis using rock and particle scanning and electron microbeam technologies, diffusion of innovation and human-nature connection frameworks. The student will become expert in technocultural aspects of social earth science, specifically geology as the interface between people and mining.

Partners and collaboration (including CASE):

Senior geologist, Dr Kabang'u Sakuwaha, has arranged the support of the University of Zambia where the student can be based during fieldwork, and will provide advice on Sustainable Mineral Resources Development. Importantly, there is provision for the student to work alongside a Zambian student on co-creation activities.

Along with collaborators at the University of Zambia, PACT (sustainability NGO with specialism in ASM and SSM) will facilitate the necessary introductions and support orientation and safe access on the ground.

Eroceht is the start-up mining company (building equitable partnerships with Zambian ASM and SSM tin miners and establishing regulatory compliance) that inspired this proposal and can engage in ongoing dialogues.

Further reading:

Johnson, C., Moore, K.R., Johnson, D., 2024. Maturing the concept of small-scale mining (SSM) in the Global North using concept evaluation criteria on the placer mining industry in Yukon, Canada. Resources Policy 91. https://doi.org/10.1016/j.resourpol.2024.104978

Johnson, C.L., Moore, K.R., Johnson, D., 2025. Understanding the motivations of small-scale miners in Yukon, Canada through a human-nature connection (HNC) framework and meaningful rural work. Extractive Industries and Society 23. https://doi.org/10.1016/j.exis.2025.101685

Moore, K.R., Moradi, S., Doyle, K., Sydd, O., Amaral, V., Bodin, J., Brito-Parada, P.R., Dudley, F., Fitzpatrick, R., Foster, P., Goettmann, F., Roberts, D., Roethe, R., Sairinen, R., Sambrook, T., Segura-Salazar, J., Thomas, G., 2021. Sustainability of switch on-switch off (SOSO) mining: Human resource development tailored to technological solutions. Resources Policy 73, 102167. https://doi.org/10.1016/j.resourpol.2021.102167

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply. You can also contact the primary supervisor for project details at k.moore@exeter.ac.uk, see also https://experts.exeter.ac.uk/21180-kathryn-moore.