MineSentinel: AI-Powered Monitoring and Forecasting for Safer and Sustainable Critical Mineral Mining

Lead supervisor: Dr., Peidong Shi, Cardiff University

Co-supervisors: Dr., Glenn Jones, Cardiff University; Dr., Doug Angus, ESG Solutions; Dr., Andy Nowacki, University of Leeds; Prof., Thomas Blenkinsop, Cardiff University; Dr., Yuhua Li, Cardiff University

Project Highlights:

- **Develop an advanced AI-powered monitoring framework** capable of automatically detecting, classifying, and locating mining-induced microseismic events and rock ruptures in near real-time, moving beyond current monitoring capabilities for proactive mining risk management.
- **Establish a proactive mining hazard forecasting system** that combines physics-informed machine learning models with high-resolution monitoring data to support safer mining operations and strengthen the resilience and sustainability of the critical minerals supply chain.
- **Acquire a unique, interdisciplinary skillset** at the forefront of mineral resource technology, including advanced geophysical monitoring techniques, the application of Artificial Intelligence to complex real-world datasets, and mining hazard management, preparing the student for a high-impact career in industry or academia.

Overview:

Meeting the UK's Net Zero goals requires a secure and substantial supply of critical minerals, driving mining into geologically complex and often hazardous environments. Sustainable extraction depends on operational safety to maintain a social license to operate. However, the risk of rockbursts, induced seismicity, and collapses is endangering lives and public trust. Current mining monitoring and hazard management systems are reactive and lack predictive capabilities needed to manage these dynamic hazards effectively. This project will address this critical gap by developing advanced microseismic monitoring toolkits and a proactive hazard management system.

This project will leverage Artificial Intelligence (AI) to go beyond conventional microseismic monitoring, enabling high-resolution source characterization and active forecasting of rock instability. In partnership with ESG Solutions (CASE partner), a global leader in microseismic technology, we will exploit AI's capacity to process vast, heterogeneous datasets from modern multi-sensor mining monitoring networks. Our first objective is to develop dedicated deep-learning models capable of automatically detecting and characterising rock-rupture events with unprecedented resolution. These high-resolution source parameters will then be integrated with physics-based geomechanical modelling to reveal the underlying rock rupture mechanisms. By combining data-driven AI and fundamental geomechanics, we will deliver a physics-informed mining hazard forecasting system, making a step change from reactive hazard monitoring to proactive, predictive risk management in critical mineral mining.

A cornerstone of this research is privileged access to vast, diverse repositories of geophysical observations provided by our CASE partner. Unlike typical datasets confined to a single site, this collection spans a broad range of global mining operations, encompassing diverse geological conditions, mining methods, and rock types. This includes microseismic recordings, acoustic emission data, and ground-truth event catalogues that explicitly label microseismic events, rockbursts, tunnel collapses, and production blasts. This diversity and scale are essential: they provide the complex, real-world training ground needed to develop robust machine learning models capable of reliably detecting, classifying, and distinguishing the subtle precursory patterns of genuine mining hazards. These unique datasets elevate our project beyond theoretical modelling and physics understanding, ensuring the resulting framework is both scientifically innovative and directly applicable to the operational challenges of the mining industry.

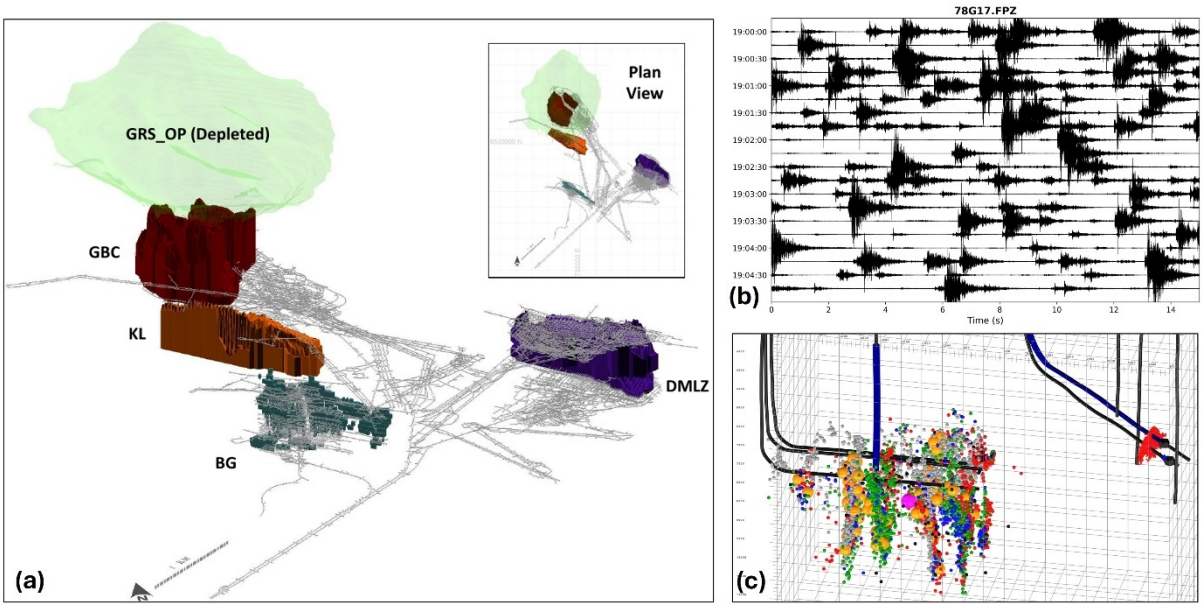

Figure 1: (a) Layout of the Grasberg Mine (Freeport-McMoRan). (b-c) Microseismic recordings and event locations at Utah FORGE.

Methodology:

This project includes three packages:

(1) AI-powered, high-resolution rock failure monitoring framework:
First, we will build an AI-powered monitoring framework trained on extensive, expertly labelled datasets. This framework will characterize rock mass failure events with unprecedented high resolution, capturing a far broader range of rock mass responses than current methods allow.

(2) Physics-constrained geomechanical modelling:
Next, these derived rock failure events will inform and constrain sophisticated geomechanical 'digital twin' simulations. The simulation will be directly informed by the extensive geomechanical expertise and tools from ESG Solutions. This will reveal the underlying physical mechanisms of rock instability and produce comprehensive, physics-grounded synthetic datasets.

(3) Physics-informed machine learning for operational mining hazard forecasting:
Finally, we aim to develop a physics-informed machine learning system that is trained on both real-world observations and our simulation data. This will create a generalizable and interpretable forecasting tool for proactive mining hazard management in critical mineral mining.

Possible Timeline

Year 1: literature review, data compilation, and development and validation of a deep-learning workflow for generating high-resolution microseismic catalogues. Visit our CASE partner (ESG Solutions) in Ontario, Canada for a two-month internship.

Year 2: construct 'digital-twin' models from field observations, perform geomechanical simulations to understand and validate rock rupture behaviours, and generate physics-constrained synthetic datasets. Visit our CASE partner (ESG Solutions) in Ontario, Canada for a two-month internship.

Year 3: develop and train physics-informed machine learning models, validate against real-world data. Visit our CASE partner (ESG Solutions) in Ontario, Canada for a two-month internship. Attend conferences, finalize PhD thesis and publications.

Training and skills:

The student will develop a sought-after interdisciplinary skillset in geophysical monitoring, AI, and geomechanical modelling. Training will be delivered through expert supervision, specialized modules from the Cardiff AI Centre, and immersive industrial placements with our CASE partner, ESG Solutions. These placements provide hands-on experience in data acquisition, processing, and analysis within active mining operations. Learning will be supplemented by auditing relevant MSc modules at Cardiff University, such as Natural Hazards and Artificial Intelligence, ensuring a comprehensive and practical educational experience.

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.

The graduate will be ideally positioned for a high-impact career in either industry or academia, driving the development of sustainable mining for energy transition.

Partners and collaboration (including CASE):

This project is built upon a close collaboration between the academic supervisors at Cardiff and Leeds, and the industry expertise of our CASE partner, ESG Solutions. The supervisory team brings specialist knowledge in machine learning, geophysical monitoring, geomechanics, and industry applications.

Our CASE partner will provide co-supervision, industrial internships, and crucial access to their extensive, proprietary global mining datasets. This real-world data is foundational for developing and validating our AI models on industry-critical challenges. This collaboration ensures the research is grounded in practical needs, providing the student with invaluable, hands-on training and a clear pathway to a high-impact career.

Further reading:

Angus, D.A., Kendall, J.M., Fisher, Q.J., Segura, J.M., Skachkov, S., Crook, A.J.L. and Dutko, M. (2010) Modelling microseismicity of a producing reservoir from coupled fluid-flow and geomechanical simulation. Geophysical Prospecting, 58(5), pp.901-914. https://doi.org/10.1111/j.1365-2478.2010.00913.x

Brady, B.H. and Brown, E.T. (2006) Rock mechanics: for underground mining. Springer science & business media. https://doi.org/10.1007/978-1-4020-2116-9

Gibowicz, S.J. and Kijko, A. (2013) An introduction to mining seismology (Vol. 55). Elsevier. https://doi.org/10.1016/c2009-0-02348-4

Shi, P., Meier, M.A., Villiger, L., Tuinstra, K., Selvadurai, P.A., Lanza, F., Yuan, S., Obermann, A., Mesimeri, M., Münchmeyer, J. and Bianchi, P. (2024) From labquakes to megathrusts: Scaling deep learning based pickers over 15 orders of magnitude. Journal of Geophysical Research: Machine Learning and Computation, 1(4), e2024JH000220. https://doi.org/10.1029/2024JH000220

Further details:

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

For queries about this project, please contact primary supervisor: Dr Peidong Shi (ship1@cardiff.ac.uk) for more information. Institution website: https://www.cardiff.ac.uk/earth-environmental-sciences.