Time dependent imaging of fracture and faulting from mine induced seismicity

Lead supervisor:

Dr. Glenn Jones, School of Earth and Environmental Sciences, Cardiff University, UK

Co-supervisors:

Dr. Peidong Shi, School of Earth and Environmental Sciences, Cardiff University, UK,

Dr. Ian Bastow, Department of Earth Science and Engineering, Imperial College London, UK

Dr. Doug Angus, ESG Solutions, Kingston, Ontario, Canada

Project Highlights:

- Characterisation and mapping the evolution of damage and fracturing in mines using novel passive seismic methods.
- Development of extensive skillsets relevant to a career in either academia or industry.
- Strong academic-industrial CASE project with access to company data, software and 3-month paid industrial placements at ESG Solutions, Canada.

Overview:

The need to decarbonise the energy and transport systems is paramount to keep Global temperatures to below 2°C and thus mitigate the worst effects of climate change. Renewable energy will play a central role in this energy revolution, which is reflected in the five-fold increase in renewable energy capacity that has occurred between 2011 and 2023. However, this energy transition requires a significant amount of resources, not least critical minerals and metals, to meet growing demand. Responsible and safe mining and quarrying is central to the extraction of these materials.

The extraction of material from a rock-mass leads to significant changes in stress and an increase in hazards not least the generation of tremors called microseismic events. Therefore, the seismic monitoring of mines provides a crucial method for mitigating seismic hazards. Moreover, the signatures and attributes of these seismic events can be analysed to optimise mineral extraction. In addition to active fracture characterisation, the propagation of the seismic waves are sensitive to variations in rock mass, such as the accumulation of damage prior to fracture. By characterising the time evolution of both these fractures and the accumulated damage, it is possible to enhance and optimise mining operations whilst reducing waste and potential environmental damage.

This project aims to map and characterise the time evolution of damage and fracturing related to mining activities using variations in the waveform characteristics and time of flight of microseismic events. The successful candidate will develop skills in signal and image processing, data analysis, machine learning, seismic wave propagation and fracture analysis. There will be opportunities for summer placements with the CASE industrial partner ESG Solutions in Canada.

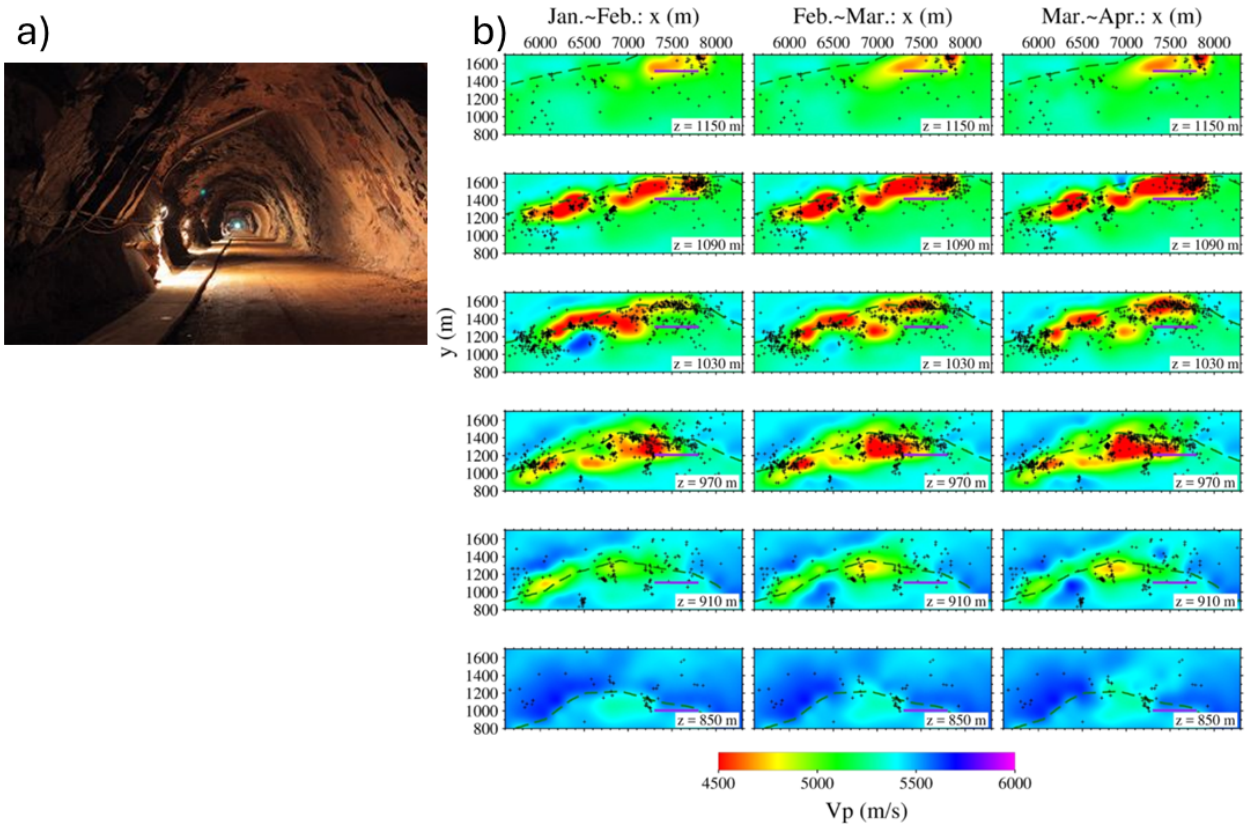

Figure 1: a) Example image of a block cave mine. Source of image https://www.canadianminingjournal.com/featured-article/block-caving/ b) Example of time-lapse microseismic P-wave velocity tomography from an underground phosphate mine. Source of image Wang et al., 2018.

Methodology:

The project will utilise a microseismic mining dataset provided by ESG Solutions. The candidate will:

i. Process mining microseismic data to determine the location, magnitude and failure mechanism of seismic events associated with mining activities. This will provide the candidate with in-depth knowledge of current industrial microseismic processing workflows.

ii. Explore the effects of fracture properties on the seismic waveform. Investigate how seismic wave attenuation relates to the physical state of the rock-mass. Understand which seismic wave parameters are sensitive to the rock fracture and what are the best methods for measuring these phenomena in experimental data.

iii. Develop and apply seismic travel time and amplitude tomographic methods to generate time-dependent maps of wave speed and attenuation. These maps will be integrated with the outputs of i. and other in-situ measurements to understand the response and evolution of fracturing and rock-mass integrity to mine activity.

Possible Timeline

Year 1: Establish an understanding of the theoretical principles of seismology as well as the practical implementation of such principles for the monitoring of induced seismicity. Gain specific knowledge of induced seismicity and industrial workflows by processing data provided by the CASE partner. The

candidate will also write a comprehensive literature review on mining induced seismicity and seismic tomographic imaging. The candidate will spend a 3 month placement with ESG Solutions where they will interpret the results of the processed data with industry experts.

Year 2: Conduct a series of numerical experiments and simulations to understand the effects of fracturing and rock damage on seismic waveforms with a strong emphasis on the attenuation of the wave. Document the sensitivity of the waveforms to differing rock fracture scenarios and how best to capture these phenomena using real data. The candidate will also begin development and testing of both travel-time and attenuation tomographic imaging for mine induced seismicity. Preparation and submission of manuscript for peer reviewed journal. Possibility of additional 3 month placement at ESG Solutions.

Year 3: Application and interpretation of the tomographic methods to the mining dataset provided by the CASE partner. The tomographic maps will be interpreted in conjunction with the source locations, magnitudes and source mechanisms of the induced microseismic events. The interpretation will focus on the geomechanical implications and impacts on mine safety and production. The candidate will prepare and submit a second manuscript for peer review. Writing and submission of PhD thesis.

The successful candidate will attend and present their findings at least 1 national and 1 international academic or industry conference. The candidate will meet with the primary Cardiff supervisory teams weekly with a project update meeting every 3 months to discuss progress and guidance. The timeline remains flexible and will be adapted based on findings and the research interests of the candidate.

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.

In addition to TARGET delivered training, the project supervisors and CASE partners will provide training in (i) microseismic processing and imaging methods, (ii) machine learning and AI methods and (iii) industrial experience with an internship with ESG Solutions. Opportunities to attend and present at national and international academic and industry facing conferences.

Partners and collaboration (including CASE):

The supervisory team has a wealth of industrial and academic experience in induced seismicity and imaging in the energy and mining sectors. The CASE partner ESG Solutions has over 30 years of experience in providing microseismic and subsurface diagnostics to the energy, mining and geotechnical sectors. The CASE partner will provide significant support through datasets, access to industry leading software and will host the student for 3 month internships in the summers of Year 1 and possibly Year 2.

Further reading:

Gibowicz, S.J. and Kijko, A., 1994. *An Introduction to Mining Seismology. International geophysics series,*(Vol. 55), Academic Press.

Rawlinson, N., Pozgay, S. and Fishwick, S., 2010. Seismic tomography: A window into deep Earth. *Physics of the Earth and Planetary Interiors*, *178*(3-4), pp.101-135.

Wang, Z., Li, X., Zhao, D., Shang, X. and Dong, L., 2018. Time-lapse seismic tomography of an underground mining zone. *International Journal of Rock Mechanics and Mining Sciences*, 107, pp.136-149.

Pyrak-Nolte, L.J., 1996, December. The seismic response of fractures and the interrelations among fracture properties. In *International journal of rock mechanics and mining sciences & geomechanics abstracts* (Vol. 33, No. 8, pp. 787-802). Pergamon.

Further details:

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

Project contact details: Dr. Glenn Jones JonesG121@cardiff.ac.uk, Cardiff University.