Seeing the Invisible: Detecting and Predicting Small Faults and Fractures in the Subsurface

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Faults and fractures play a critical role in many energy-transition applications. They can provide pathways for fluid migration, influencing the security of geological CO_2 storage and the circulation of fluids in geothermal reservoirs. At the same time, faults can represent a hazard, particularly where subsurface fluid injection or extraction has the potential to reactivate them and generate induced seismicity. Understanding where faults and fractures occur is therefore essential for the safe and effective use of the subsurface and well integrity.

Three-dimensional seismic reflection data provide one of our most powerful tools for imaging faults at depth. Faults are typically recognised through offsets or disruptions of seismic reflections. However, conventional manual interpretation tends to focus on the largest and most clearly resolved structures. Networks of smaller faults and fractures may therefore remain undetected, despite potentially having a major influence on subsurface fluid flow and mechanical behaviour.

This PhD will ask:

Can modern machine-learning and geomechanical modelling approaches allow us to detect and predict small-scale faults and fractures that have previously remained invisible in seismic data?

The project will integrate 3D seismic imaging, borehole observations, machine learning and geomechanical modelling to investigate deformation across a range of scales.

The research will initially use high-quality 3D seismic datasets to map fault networks using conventional interpretation, seismic attributes and modern deep-learning approaches. Pre-trained and fine-tuned models will be used to investigate whether subtle deformation can be extracted beyond that routinely identified through manual interpretation (e.g. Hao et al. 2025).

These observations will be compared with fractures identified directly in borehole image logs. This provides an opportunity to bridge the scale gap between faults that can be resolved in seismic data and much smaller fractures observed in wells. The project will test whether patterns in seismic attributes or machine-learning fault extractions can be related to, and ultimately used to predict, variations in fracture intensity observed in boreholes.

A complementary strand of the project will use SLB geomechanical modelling software to investigate where small-scale deformation is expected to develop given the tectonic and depositional history of an area (Souza et al. 2025). The resulting forward models will be converted into synthetic seismic datasets, allowing direct comparison between predicted deformation and the structures visible, or potentially hidden, in real seismic data.

By bringing these approaches together, the project will test whether independently derived predictions from geomechanical models, borehole observations and machine-learning analysis identify deformation in the same locations.

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Research objectives

The project will:

1. **Detect** small-scale faulting in 3D seismic data using deep learning and seismic attributes.
2. **Quantify** fracture distributions from borehole image logs and investigate their relationship to seismically imaged faults.
3. **Model** the development of small-scale deformation around larger fault systems using geomechanical simulations.
4. **Validate** predicted deformation using synthetic seismic data, real 3D seismic observations and borehole fracture measurements.
5. **Develop** a workflow for predicting fault and fracture intensity away from areas of direct borehole control.

Why does this matter?

The ultimate goal is to move from simply identifying the faults that we can see towards **predicting the deformation that we cannot**. If successful, the project will provide a new approach for assessing small-scale fault and fracture distributions in areas with limited drilling information, and potentially only 2D seismic data.

Such capability will have significant applications in geothermal energy, geological gas and CO_2 storage and other subsurface energy technologies, where understanding fracture networks is critical for predicting fluid flow, reservoir behaviour, well integrity and geomechanical risk.

Who should apply?

This interdisciplinary project would suit candidates with a background in geoscience, geophysics, geology, engineering or a related discipline. It would also suit candidates from computational, mathematical or physical-science backgrounds who are interested in applying modelling, machine learning and data visualisation to Earth science and energy-transition problems. Prior experience in all aspects of the project is not expected and necessary training will be provided. Enthusiasm to integrate datasets with a focus on the energy transition is essential.

References

Hao, Y., Bell, R.E., Cader, A., Wang, Y., 2026. Prediction of fault and fracture density from seismic attributes and machine learning models calibrated with borehole image logs. Basin Research 38 (3)

Souza, J.A.B., Santos, L.E., Falcão, T., Bizotto, A.C., Mohamad-Hussein, A., Garcia-Teijeiro, X., and B.N. Macedo. 2025. “The Role of Geomechanics in Integrated Forward Modelling of Geological Processes." Paper presented at the 59th U.S. Rock Mechanics/Geomechanics Symposium, Santa Fe, New Mexico, June 2025.

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