Controls of Pore Fluid Pressure on Fault Slip Modes: Implications for Injection Induced Seismicity.

Summary

Fluid injection in rock reservoirs produces high pore pressures, which may create small tensile/shear fractures within the reservoir volumes. Such newly created hydrofracture systems may produce microseismic activity, and favour along-fault fluid flow, which may weaken and reactivate pre-existing, larger faults. This PhD project aims to investigate the control exerted by pore fluid pressure on fault slip mode (e.g. stable & aseismic vs. unstable & seismic) and earthquake rupture propagation behaviour (slow vs. fast slip events). The project will involve conducting rock mechanics experiments on shale, sandstones, limestones and granite rock samples, and collecting microstructural observations to infer the main deformation processes. This project addresses the fundamental issues associated with injection induced seismicity during hydraulic fracturing activities in tight and geothermal reservoirs. Hence, it is extremely timely as this topic leads the low carbon energy transition agenda in the UK, Europe and worldwide too.

Background

Fluid injection in rock reservoirs induces hydraulic fracturing, which enables permeability of rock reservoir to be artificially enhanced. Scaling relationships between fracture/fault size and injected pore fluid volume predict that induced hydrofracturing should only produce microseismic activity, which is associated to the creation of small tensile/shear fractures contained within the reservoir volumes (Zoback, 2012).

However, larger than predicted magnitude events have still been associated to fluid injection during “fracking” (e.g. 2011 Mw 2.3 –Lancashire, UK; Clarke et al., 2014) and geothermal energy (e.g. 2017 Mw 5.5 in Pohang, South Korea; Grigoli et al., 2018) activities. Such events have been interpreted as due to the reactivation of larger pre-existing faults within the basement and the overburden beneath and above the target reservoir formations, respectively.

To date, the role played by pore fluid pressure on the slip behaviour of reactivated, pre-existing faults is still poorly understood. In particular, the links between diagenetic composition and fault slip behaviour with pore pressure is poorly explored and understood.

Aims and Objectives

In this project, the student will investigate the role of pore fluid pressure on fault slip mode (e.g. stable & aseismic vs. unstable & seismic) and earthquake rupture propagation behaviour (slow vs. fast slip events) by conducting triaxial failure tests on shale, sandstones, limestones and granite rock samples. Characterisation of the different rock type in terms of their mineralogical and lithological makeup will be performed to explore the links between diagenetic composition and fault slip behaviour with pore pressure. Scaling relationships will also be obtained, linking the seismic parameters of the reactivated fault (e.g. amount of slip, rupture size, earthquake magnitude, stress drop) with the injected pore fluid volume, pressure and injection rate.
The main purpose of our research is to investigate the physics of fluid driven earthquakes and to identify the key controls on fault slip behaviours. The expected results will help evaluating the risk associated with induced seismicity and potential along-fault fluid flow during hydraulic fracturing in tight oil and gas- and geothermal reservoirs.

**Methodology**

This student will perform triaxial failure tests on shale, sandstones, limestones and granite rock samples under different pore pressure regimes. The effects of primary loading controls on fault slip behaviour (e.g. loading rate and fault healing) will be systematically investigated during triaxial loading experiments on simulated faults.

Microstructural observations using optical microscope, SEM and TEM high resolution images will be performed on the deformed samples to infer the dominant deformation mechanisms associated with aseismic and seismic slip behaviour.

The student will first derive scaling laws for laboratory events by relating measured seismic parameters (e.g. events number, stress drop, event magnitude, rise time, etc.) to imposed experimental conditions (e.g. pore pressure, pore volumes, loading rate). Then, laboratory derived scaling laws will be compared and upscaled to those already existing in the literature for natural induced seismicity.

The purpose of the comparison and upscaling from the laboratory to nature is to check whether laboratory induced earthquakes obey the same physics of natural induced earthquakes.

**Timeline**

**Year 1:** Literature review on theoretical and case studies of induced seismicity. Training in rock mechanics experiments and acquisition of microstructural observations using SEM and TEM facilities available in house. Setting up and performing of preliminary mechanical experiments and data processing techniques. Training in project specific and transferable skills.

**Year 2:** Further performing of triaxial loading experiments, microstructural observations, and data processing and interpretation. Writing of first draft of academic publication.

**Year 3:** Collate the scientific results produced in several scientific publications; these will be combined with further chapters to integrate into a first draft of the PhD thesis.

**Year 4:** Project completion: finalizing thesis and submission of scientific manuscripts.

**Training & Skills**

The student will become part of the CDT in Geoscience and Low Carbon Transition, which offers a multidisciplinary package of training. The student will benefit from the combined strengths and expertise that is available across our partner organizations.

The student will benefit from a vibrant research culture in the department of Earth Sciences, in which ~70 PhD students work on a wide range of Earth Science research projects. In particular, Geoenergy and Structural Geology form research clusters in the department of Earth Sciences, and have dedicated group meetings and seminars.

Training will be provided in structural geology, rock, fault and earthquake mechanics (performing triaxial experiments and processing experimental mechanical data). In addition, the student will receive training in general and transferable skills.

The student is expected to attend national and international conferences to disseminate research results and to spend time away from Durham to integrate all project partners at the partner institutes.

**References & Further Reading**


**Further Information**

For further information on the PhD project, the department of Earth Sciences or doing a PhD in Durham, please feel free to contact Nicola De Paola (nicola.de-paola@durham.ac.uk).