Forecasting of catastrophic failure in porous media

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**Summary**

Catastrophic brittle failure of porous materials results from the co-operative behaviour of a large population of growing micro-cracks, eventually organising themselves to produce a through-going fault. In this project, you will directly image this process in three dimensions in laboratory rock samples undergoing deformation, using state-of-the art X-ray micro-tomography and micro-seismic monitoring (Fig 1 below), and test a range of hypotheses for forecasting the failure time as a function of a range of controlling variables, including the initial microstructure of the sample. The aim is to use the results to improve the accuracy and precision of failure forecasts, and to examine how the process scales in space and time to induced and natural seismicity.

**Figure 1:** A) Our x-ray transparent triaxial press in operation at the SOLEIL Synchrotron, Paris; B) Damage in a 3mm diameter Ailsa Craig microgranite sample visualised at peak differential stress, immediately before failure - note localisation of microcracks along the final plane of failure; C) Classic acoustic emission (AE) event rate evolution during deformation, with an exponential rise as damage initiates giving way to rapid acceleration close to peak stress, followed by abrupt failure of the sample.

**Background**

Catastrophic failure often occurs with very little warning, for example in sudden-onset disasters such as earthquakes. In other applications, there may be some warning from precursors such as changes in seismic wave velocity or in the statistical properties of smaller shocks and acoustic emissions associated with localised small faults and fractures, for example prior to volcanic eruptions, landslides and rock-falls, and in seismicity induced by engineering of the subsurface. There are many hypotheses for the evolution of such precursors, and for associated methods of estimating the timing of system-sized catastrophic events. A key determinant of the accuracy of failure forecasts in the deformation of laboratory rock samples is the microstructure of the porous material inferred from the porosity of the sample using a simple model of overlapping spheres and an appropriate rock physics model that takes account of crack-crack interactions\(^ {1,2}\). In this project you will test this hypothesis using direct imaging of the microstructure in a CT scanner and synchrotron. The aim is to develop a more accurate forecasting model for system-sized catastrophic failure, as well as using the results to modify the models to account for the starting microstructure, and the way precursors scale in space and time.

1. Exponential rise in AE rate with onset of cracking
2. Precursory supra-exponential acceleration around peak stress
3. Rapid failure
Research aims
- To improve the accuracy of forecasting catastrophic failure
- To test the hypothesis that microstructure controls this accuracy
- To update the relevant rock physics models to incorporate this systematic effect
- To investigate the scaling of precursors to larger systems loaded at slower strain rates

Method
You will assist in carrying out experiments on catastrophic failure in real and synthetic rocks using a new X-ray transparent deformation cell, constructed as part of a recently funded NERC grant. This will include stints at the ‘Diamond’ synchrotron facility. You will analyse the results to produce sharp images of the 3D structure, and compare its properties to those of a model based solely on inference from the porosity. You will then test a variety of hypotheses for the acceleration to failure of acoustic emission event rate as deformation localises, informed by the evolution of the 3D microstructure using point process modelling in a Bayesian framework. The results will be used to improve understanding of the models, and practically to develop systematic corrections to the predicted failure time as a function of the starting microstructure. Finally, you will examine the scaling of precursors in samples of different sizes loaded at different strain rates, to examine the reasons precursors may be harder to detect for larger systems loaded at smaller, more natural, strain rates.

Training
You will be trained in assisting with the execution of laboratory rock deformation experiments, and in handling and analysing large X-ray CT data sets, as well as in micro-seismic monitoring of samples undergoing deformation. The data analysis will be carried out using Bayesian techniques that account formally for prior information and constraints, after appropriate training. This will include both specialist scientific training and generic transferable and professional skills, through attendance at relevant University- level and School courses.

Applicant requirements
You will have a first degree in geophysics, physics, mathematics or statistics, and be comfortable with analysis of uncertainty in complex systems. You will also be competent in computer programming, and be willing to learn more. Evidence of good communication skills in oral and written presentations would be a significant advantage.

References