The University of Oxford Department of Earth Sciences

EARTHSCIENCES

UNIVERSITY OF OXFORD

Granular dilatancy and the mechanics of faults

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Key Words	**fault mechanics, earthquakes, continuum mechanics, granular media, mathematics**

This project is suitable for applicants with a training in continuum mechanics, fault mechanics, engineering mechanics or physics and applied mathematics more broadly.

Overview

Many faults that generate earthquakes are clogged with water-saturated gouge. This granular medium likely plays a role in the fault response to stress, whether that be creep, frequent stick-slip sliding, or locking followed by major rupture.

The dynamics of faults are typically modelled with rate-and-state friction, a formulation with an empirical basis that can describe a range of fault behaviours. The physical basis for rate-and-state friction remains unclear.

This project will address the question of whether and how fault gouge gives rise to rate-and-state behaviour of faults, and what that implies for our understanding of fault mechanics more broadly. It might help us to understand how and when large ruptures occur.

The dynamics of granular media have been studied extensively by the physics and engineering communities, but have been incorporated into relatively few theories in geoscience. Indeed, dilatancy is recognised as an important component of fault deformation, but it is usually included in an empirical and somewhat untested manner. Fault mechanics brings challenges that are not typically treated by physicists: large variations in temperature, long timescales, polydispersivity of grains, creep deformation of grains including by low-temperature plasticity, and mechanical coupling with groundwater flow in a heterogeneous permeability structure.

This project will develop theory for fault granular mechanics. It will begin with simple, highly idealised models and add physical complexity motivated by hypotheses and constrained by laboratory experiments. It will ultimately test whether granular mechanics helps to rationalise the diverse modes of fault behaviour and the transitions between them.

Methodology

The project will be theoretical and mathematical in nature, using continuum mechanics as a framework. It will likely draw on observational data from earthquakes as well as laboratory studies of deformation of granular media.

Theory will be investigated with the full spectrum of techniques including scaling analysis, asymptotics, analytical solutions and numerical solutions.

The project will draw on the literature of rock mechanics and fault mechanics, but also on physics, engineering and applied mathematics.

Potential Observational Targets

As the project develops our understanding of dilatancy-controlled fault deformation, it will assess dilatancy's role in large-scale processes in the Earth.

For instance, the project may assess why many creeping, nominally stable faults have small patches that rupture in earthquakes. Such patches are often interpreted to be composed of a different rock type. But there is no clear evidence for a different rock type. Perhaps earthquake patches arise because fault geometries localise high stresses and permeabilities, making dilatancy more or less effective.

Alternatively, the project may examine slow earthquakes — ruptures that start accelerating but then stall at low slip rates rather than reaching the m/s speeds of "normal" earthquakes. It may assess whether dilatancy and pore pressure variations can control these events and explain their properties. For instance, most slow slip events (around the world) have stress drops of order 10–100 kPa. Could that stress drop be a simple function of dilatancy at depth? And what should happen at the edge of the slow slip region, where normal earthquakes begin? The project may examine dilatancy's predictions for spatial variation in slip and for the interactions between slow and fast earthquakes.

Timeline

Year 1: Literature survey and preparatory coursework.

Years 2 - 3: Theory development, idealised modelling, incorporation of physics.

Year 3 - 4: Hypothesis testing by comparison with observations.

Training & Skills

The project requires an interdisciplinary skill set including applied mathematics, continuum mechanics and geophysics. The training will aim to fill gaps in knowledge and skills. For example, the student might take a graduate-level course in scientific computing, and may follow other courses in mathematics, materials science or Earth science as appropriate. Attendance at a summer school is expected, depending on availability.

The student will also learn through weekly project meetings with the supervisors. A key focus will be on scientific writing and illustration for publication.

Other courses on professional skills are available through the University. Attendance is encouraged.

References & Further Reading

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Further Information

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