The University of Oxford Department of Earth Sciences

EARTHSCIENCES

UNIVERSITY OF OXFORD

From dislocations to subduction: the microphysics of olivine deformation and its geodynamic implications

Supervisory Team	• **Prof Richard Katz -- https://www.earth.ox.ac.uk/people/richard-katz** • **Prof Peter Howell -- https://www.maths.ox.ac.uk/people/peter.howell**
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Key Words	**rock mechanics, geodynamics, mathematics, modelling**

This project is suitable for applicants with a training in physics, geophysics, materials science, applied mathematics, theoretical and applied mechanics, engineering or geophysical fluid dynamics. The student could become part of either the Department of Earth Science or the Mathematical Institute, but the research would be based in the use of mathematics and computation.

Overview

The dynamics of plate tectonics and mantle convection are inseparably coupled. Rigid oceanic plates are made from the same material as the ductile mantle below, but are much colder. Their thermal contraction causes them to sink (subduct) back into the mantle. The rheological properties of rock, which define its material response to stress, control the dynamics of subduction and other geodynamic processes. These properties of mantle rocks have generally been determined using laboratory deformation experiments that are fit by flow laws. The empirical fits are extrapolated over many orders of magnitude in rates to inform geodynamic models. This extrapolation, lacking any grounding in the microphysics of deformation, must be considered hypothetical at best.

A new, physics-based theory for olivine deformation has recently been derived at Oxford. This theory describes the evolution of dislocation density in deforming, polycrystalline rock. It is a scalar theory that explains a variety of features in uniaxial deformation experiments, spanning a range of temperature, stress, stress changes, and grain size. Its application to mantle conditions makes distinct predictions, but those predictions remain largely unexplored.

This project aims to extend the mechanical theory of dislocation-density evolution, further test it against laboratory experiments, and apply it to geodynamic contexts such as subduction and postglacial rebound.

Methodology

The project will take a mathematical approach to investigating the relevant physics. A key step will be to extend the mechanical theory of dislocation-density evolution and associated stresses from scalar to tensor format. A mathematically self-consistent and computationally tractable theory will be derived from fundamental thermodynamic principles, using experimentally supported constitutive relations and asymptotic analysis. This new theory will be tested and calibrated against forthcoming laboratory experiments on multi-axial deformation.

The project will then use the rheological theory to develop idealised models of rock deformation in simplified geometries. The qualitative behaviour of the models will be analysed using perturbation theory to build insight into the large-scale dynamic implications of the theory.

Finally, the project will develop two-dimensional, tectonic-scale geodynamic models of mantle flow in response to changing stress. Bending of the lithosphere into subduction zones will be a key target, but applications to post-seismic and post-glacial deformation might also be considered. This last step will involve the use of two-dimensional numerical models that will be developed using an in-house code framework.

Timeline

Year 1: Literature survey and preparatory coursework. Initial theory development for tensorial mechanics of dislocation density. Initial comparison to lab experiments.

Years 2 and 3: Completion, testing and publication of tensorial theory. Development and analysis of idealised models and/or large-scale geodynamic models.

Year 4: Development of large-scale geodynamic models. Publication of applications of the theory.

Training & Skills

The student will 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 fluid dynamics 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

Dislocation theory of steady and transient creep of crystalline solids: predictions for olivine. Breithaupt, Katz, Hansen & Kumamoto. *In review; email to request a copy.*

Hansen, L. N., Kumamoto, K. M., Thom, C. A., Wallis, D., Durham, W. B., Goldsby, D. L., ... & Kohlstedt, D. L. (2019). Low-temperature plasticity in olivine: Grain size, strain hardening, and the strength of the lithosphere. Journal of Geophysical Research: Solid Earth.

Hansen, L. N., Wallis, D., Breithaupt, T., Thom, C. A., & Kempton, I. (2021). Dislocation creep of olivine: Backstress evolution controls transient creep at high temperatures. Journal of Geophysical Research: Solid Earth.

Further Information

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