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Toward a unified creep law for olivine in the upper mantle

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Olivine constitutes between 40% and 80% of the volume of the upper mantle. Therefore, the rheological properties of olivine must control the rheology of the upper mantle. Most of the mantle exhibits a ductile, viscous rheology. This is also the case of olivine when deformed at high temperature as shown in many experimental studies performed in the last decades. In this temperature range, a power law can describe the rheology of olivine. Depending whether diffusion creep or dislocation creep is activated, this rheology is linear viscous or exhibits a stronger stress sensitivity. However, in the uppermost mantle, the rheology of olivine is more complex and less understood. It is however recognized that the power law breaks down and a distinct rheological regime described by an exponential law is usually invoked.

The aim of the present work is to understand the transition between the power and the exponential laws for the range of temperatures (800 K < T < 1700 K), and stress (100-500 MPa). For that purpose, we used a numerical modeling approach based on 2.5-Dimensional (2.5-D) dislocation dynamics simulations. This technique is very well adapted to describe complex dynamic processes involving dislocations. Recently, it has proved to be able to well describe power law creep involving [100] dislocations in olivine at high temperatures (T>1400K). Applied to [001] dislocations at low temperature (T<1200K), this creep law has also been able to reproduce exponential law creep. However, being conducted with different dislocation slip systems and disconnected temperature intervals, these models could not shed light on the transition between those two regimes. In this work, we consider a unique deformation mechanism, which is modeled in a wide temperature range from 800 K to 1700K. This model reproduces the power law breakdown, which is driven by stress only and occurs for stresses higher than 200 MPa. Based on the observation that the power law breakdown does not correspond to a change in deformation mechanism, we conclude that the use of two rheological laws to describe the creep of olivine can be motivated by convenience, but is not imposed by theoretical needs. Alternatively a unified creep law can be proposed to describe the rheology of olivine in a wide range of temperature relevant for the upper mantle. This flow law may have an exponential form and describe the entire range of experimental data, from room temperature to 1800K at both low and high stresses, using a single adjusting parameter called mechanical resistance. However, the exponential form is not required for theoretical reasons. Thus we also propose an alternative mathematical expression based on a polynomial form, which is more suitable for implementation in geodynamical models.