EXPERIMENTAL CONSTRAINTS ON THE STRENGTH OF THE LITHOSPHERES OF TERRESTRIAL PLANETS. David. L. Kohlstedt and Stephen. E. Schneider, University of Minnesota, Department of Geology and Geophyiscs, Pillsbury Hall, Minneapolis, MN 55455 (David Kohlstedt, dlkohl@umn.edu; Stephen Scheneider, sschneider@marathonoil.com).

Introduction: Our research focuses on an experimental investigation of the viscosity of upper mantle minerals and rocks under the relatively *low-temperature*, *high-stress* conditions characteristic of the lithospheres of the terrestrial planets. While an extensive literature exists on the rheological properties of mantle rocks at high temperatures and low differential stresses typical of the asthenosphere of a terrestrial planet, relatively little is known about the *deformation behavior at lithospheric conditions, where flow occurs by mechanisms not sampled in high-temperature experiments*. Flow laws describing deformation under lower temperature, higher stress conditions are currently based either on the micro-indentation experiments of Evans and Goetze [1] or the load-relaxation experiments of Raterron et al. [2] carried out with a D-DIA-type cubic-anvil apparatus; the uncertainties in both are large.

We are bridging the high-resolution results obtained at high temperatures and low stresses in a gas-medium apparatus and those obtained at lower temperatures and higher stresses in low-resolution indentation and load-relaxation experiments, thus producing a reliable flow law describing deformation under lithospheric conditions. To do so, we carry out experiments on olivine single crystals in a high-resolution gas-medium apparatus at temperatures between 500^o and 1200^{o}C and a confining pressure of 300 to 500 MPa. By using single crystals, it is possible to deform samples at differential stresses that substantially exceed the confining pressure while remaining fully within the plastic flow field (i.e., without microfracturing and cracking samples), as is necessary to obtain robust deformation data and a flow law appropriate for the lithospheric mantle of a terrestrial planet. Such a constitutive equation provides an essential constraint for modeling the thermomechanical properties and deformation behavior based on satellite images of tectonic structures combined with topography and gravity data.

Experimental Design: We have carried out triaxial compressive creep experiments on olivine single crystals in a high-resolution gas deformation apparatus in order to extend the experiments on single crystals to lower temperatures and high stresses than previously employed. Samples are enclosed thick-walled Ni capsules. In our experiments, the strength of Ni is less than 5% of that of olivine; measured loads are corrected for the strength of the Ni sleeve to obtain the load on and strength of the samples. We have deformed single crystals of San Carlos olivine deformed in compression along either the $[110]_c$, $[101]_c$, or $[011]_c$ direction. The subscript indicates that the axes are referenced to those of a cubic crystal; for example, a sample deformed along $[110]_c$ was oriented such that the load was applied at 45^o to the [100] and [010] crystallographic directions of the olivine crystal.

Experimental Results: Results from our recent triaxial deformation experiments on olivine crystals compressed along $[101]_c$ at temperatures of 900^o to 1200^{o}C, a confining pressure of 300 MPa, and differential stresses of 100 to 1000 MPa are reported in [5] and plotted as differential stress versus temperature in Figure 1. Data deviate from the high-temperature flow law at ~1300^{o}C and follow the low activation energy branch of the high-temperature Bai et al. [4] flow law down to ~1000^{o}C, at which point the data approximate the low-temperature flow law of Raterron et al. [2]. Agreement amongst the results from our nine experiments is excellent. Agreement with previously published results on $[101]_c$ crystals is very good.

Results from our recent triaxial deformation experiments on olivine crystals compressed along $[110]_c$ under similar conditions are summarized in the semi-log plot of stress versus temperature in Figure 2. Data closely follow the high-temperature Bai et al. [4] flow law down to ~1000^{o}C, at which point the data approximate the low-temperature flow law of Evans and Goetze [1]. Agreement amongst our results and with those of other studies is excellent.

We have also completed low-temperature experiments on crystals oriented for compression along $[011]_c$. The results for all three orientations are summarized in Figure 3. At *high temperatures (low stresses)*, the relative strengths lie in the order $[110]_c < [101]_c < [011]_c$, while at *low temperatures (high stresses)* the order is $[101]_c < [011]_c < [110]_c$. This important result provides direct information on the relative contributions of different slip systems to deformation under lithospheric conditions and thus on the evolution of microstructure during deformation (e.g., lattice preferred orientation, LPO).

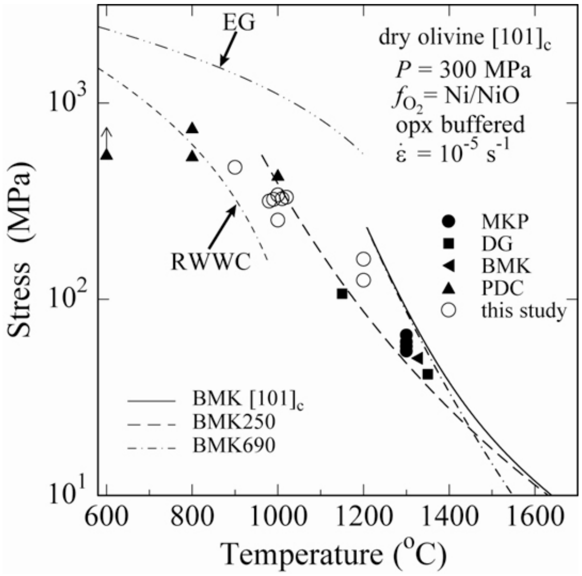

Figure 1: Semi-log plot of differential stress versus temperature for our samples deformed at a strain rate of 10^{-5} s^{-1}. Included are data from previous studies on $[101]_c$ oriented olivine crystals from MKP: Mackwell et al. [5], DG: Durham and Goetze [6], BMK: Bai et al. [4], and PDC: Phakey et al. [7]. Also plotted are the low-temperature flow laws for polycrystalline samples from EG: Evans and Goetze [1] and RWWC: Raterron et al. [2]. In addition, the Bai et al. [4] composite constitutive equation for the $[101]_c$ orientation (BMK) as well as the component flow laws BMK690 and BMK250 are shown. BMK690 and BMK250 indicate activation energies of 690 and 250 kJ/mol. After Demouch et al. [3].

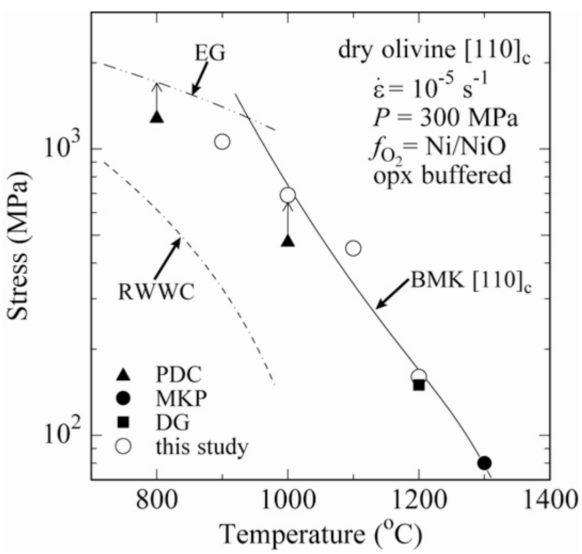

Figure 6: Semi-log plot of differential stress versus temperature for our $[110]_c$ crystals deformed at a strain rate of 10^{-5} s^{-1}. Included in this plot are data from previous studies on $[110]_c$ crystals from MKP: Mackwell et al. [5], DG: Durham and Goetze [6], and PDC: Phakey et al. [7]. Also plotted are the low-temperature flow laws for polycrystalline samples from EG: Evans and Goetze [1] and RWWC: Raterron et al. [2]. In addition, the Bai et al. [4] composite constitutive equation for the $[110]_c$ orientation (BMK) is shown.

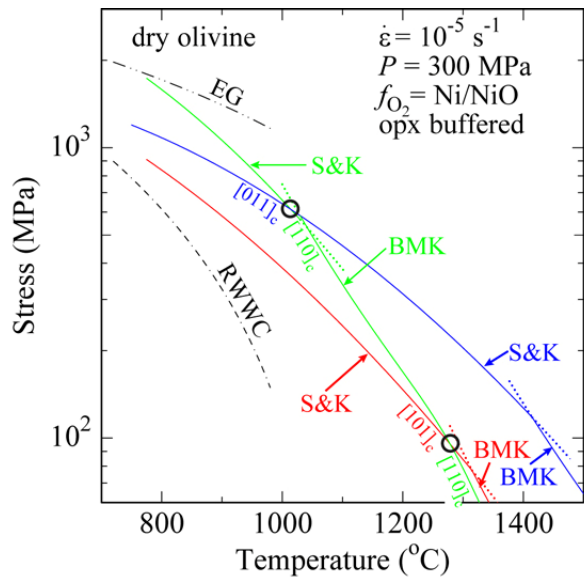

Figure 7: Semi-log plot of differential stress versus temperature summarizing data from our low-temperature experiments for $[110]_c$, $[101]_c$ and $[011]_c$ crystals deformed at a strain rate of 10^{-5} s^{-1} under anhydrous conditions. The transition from our lower temperature results to the high-temperature flow laws of Bai et al. (BMK) [4] are indicated by the short segments of dotted lines. In addition, the low-temperature flow laws for polycrystalline samples from EG: Evans and Goetze [1] and RWWC: Raterron et al. [2] are shown. Note the crossovers in *relative strength* of the various slip systems indicated by open circles: At *high temperatures*, $[110]_c < [101]_c < [011]_c$. At *low temperatures*, $[101]_c < [011]_c < [110]_c$.

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