INFLUENCE OF Fe CONTENT ON THE CREEP PROPERTIES OF OLIVINE. Y.-H. Zhao[1], M. E. Zimmerman[2] and D. L. Kohlstedt[2], [1]Deptartment of Geophysics, Peking University, Beijing, 100871, China, zhaoyh@pku.edu.cn;, [2]Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN, 55455, U.S.A., zimme030@umn.edu, dlkohl@umn.edu.

Introduction: The rheological properties of olivine govern mantle convection and lithospheric strength on terrestrial planets. Earth's mantle is relatively poor in Fe with ~8 wt% FeO compared to the martian mantle with ~18 wt% FeO [1]. The high-temperature, high-pressure rheological properties of the more Fe-rich martian mantle may differ substantially from those of Earth's mantle. Although a number of experimental studies have addressed the effects of temperature, pressure, oxygen fugacity, water content, and melt fraction on aggregates composed of ~Fo_{90} olivine [2], none have explored the influence of Fe content on the viscosity of Mg-Fe olivine.

In this study, we investigate the influence of Fe content on the rheological properties and deformation-produced fabrics of olivine-rich rocks. Our study builds on the observation that, at a given temperature, the viscosity of natural single crystals of Fo_{90} San Carlos olivine [3] is significantly higher than that of synthetic crystals of Fo_0 fayalite [4]. Nonetheless, little is known about the change in rheological properties associated with changes in Fe content in olivine. Therefore, we have undertaken an experimental investigation of the effect of iron content on the viscosity and lattice preferred orientation (LPO) of olivine aggregates in order to provide a basis for comparing models of convection for the mantle of Earth with those for the more iron-rich mantle of Mars.

Experimental Details: To investigate the effect of Fe content on the rheological behavior of olivine, the high-temperature, high-pressure compressive creep experiments were performed on aggregates of Fo_{50} and Fo_{70} in a gas-medium deformation apparatus. To study microstructural development in these samples, high-strain torsion experiments were carried out in a gas-medium torsional deformation apparatus. The results from both types of experiments are compared with those for San Carlos olivine, Fo_{90}, in order to quantify the influence of Fe content.

To fabricate samples of Fo_{50} and Fo_{70}, fayalite powder was first synthesized in a one-atmosphere furnace from high-purity powders of Fe_2O_3 and SiO_2 in a molar ratio of 1:1.002. This non-stoichiometric ratio was used to ensure that the samples were buffered by enstatite. Next, this Fo_0 powder was mixed in appropriate proportions with powdered San Carlos olivine, Fo_{90}, and annealed at 1670 K in a one-atmosphere furnace for 16 h in a flowing mixture of CO plus CO_2 gas to buffer the oxygen partial pressure within the stability field of fayalite. The resulting chemically homogeneous powders were ground to a particle size of <10 μm in preparation for hot-pressing.

These Fo_{50} and Fo_{70} powders were cold-pressed into Ni capsules, the ends of which were covered by Ni discs, and then hot-pressed at 300 MPa, 1533 K for 2 to 12 h. The average grain size of the resultant hot-pressed samples was between 29 and 38 μm, and the final densities were >98% of the theoretical value.

Hot-pressed samples were subsequently dried at 1330 K for 10 h in a one-atmosphere mixture of CO + CO_2 gas at an oxygen partial pressure of 10^{-13} atm. The samples were then inserted into nickel sleeves ~0.3 mm thick to set the oxygen fugacity near the Ni:NiO solid-state buffer during an experiment This assembly was inserted into a 0.3 mm thick iron jacket along with alumina and zirconia pistons [5].

Triaxial compressive creep experiments were carried out in a servo-controlled, internally heated gas-medium apparatus at 50 K intervals between 1323 and 1473 K and a confining pressure of 300 MPa with differential stress of 10 to 300 MPa. The load on the sample was measured with a load cell located inside the pressure vessel and corrected for the load supported by the nickel sleeve and iron jacket. For each sample, creep tests were performed at several differential stresses, σ, at a constant temperature to determine the stress exponent or at several temperatures to determine the activation energy for creep. A sample was first deformed at 1473 K at several differential stresses and then at lower temperatures, again at several stress levels. The total strain in a compressive creep experiment was ~20%.

Constant angular displacement rate torsion experiments were performed in a gas-medium apparatus at 1473 K to shear strains of $\gamma \approx 4$ at a shear stress of ~100 MPa. The torque on the sample assembly was measured with an internal torque cell.

In both types of experiments, temperature fluctuated by <5 K over the duration of an experiment, and the temperature gradient along a sample was maintained at <0.05 K/mm.

Experimental Results:

Creep results. Creep experiments on samples of Fo_{50} and Fo_{70} yield a stress exponent of n =3.7 at $\sigma >$ 50 MPa, as illustrated in Figure 1, and an activation energy, Q, of 460 to 480 kJ/mol.

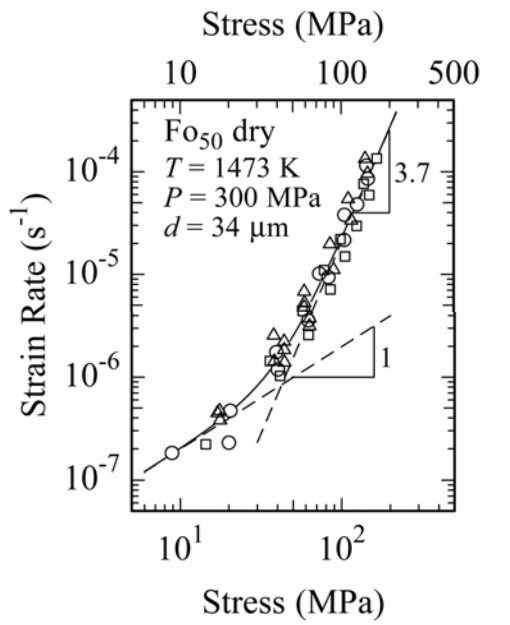

Figure 1: Creep data for samples of Fo_{50} fall in the transitional regime between diffusion creep with n =1 and grain boundary sliding creep with n =3.7.

As illustrated in Figure 2, samples of Fo_{50} are weaker than those of Fo_{70} which are weaker than samples of Fo_{90}.

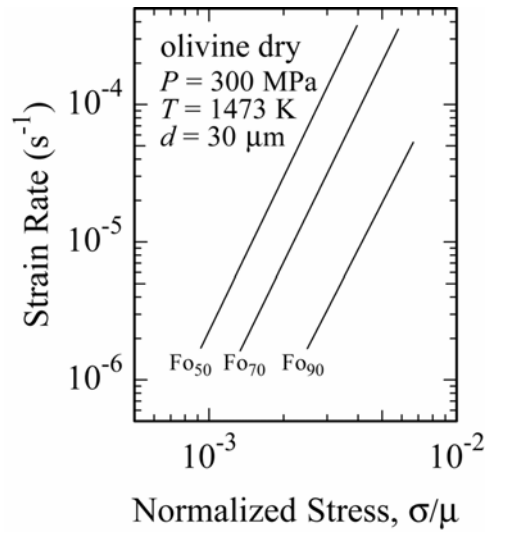

Figure 2: Comparison of flow laws for samples of Fo_{50}, Fo_{70}, and Fo_{90} illustrate that strength and viscosity decrease with increasing Fe content.

Creep results for all three compositions can be fit to the following constitutive equation, which takes into account the dependence of strain rate on stress, temperature, and Fe (faylaite) content, X_{Fa} [7]:

$$\dot{\varepsilon} = \dot{\varepsilon}_o \left(\frac{\sigma}{\mu}\right)^n \left(\frac{b}{d}\right)^2 X_{Fa}^{\,p} \exp\left(-\frac{(Q_o + \alpha X_{Fa})}{RT}\right) \qquad (1)$$

where $\dot{\varepsilon}_o$ is a materials parameter, μ shear modulus, b Burgers vector, d grain size, $Q = Q_o + \alpha X_{Fa}$ with α a fitting constant, R the gas constant, and T temperature.

Torsion results. Samples deformed to γ >2 exhibit a marked shape preferred orientation (SPO), Figure 3, and a strong LPO, Figure 4. The LPO indicates that (010)[100] was the dominant slip system, similar to observations on samples of Fo_{90} [6].

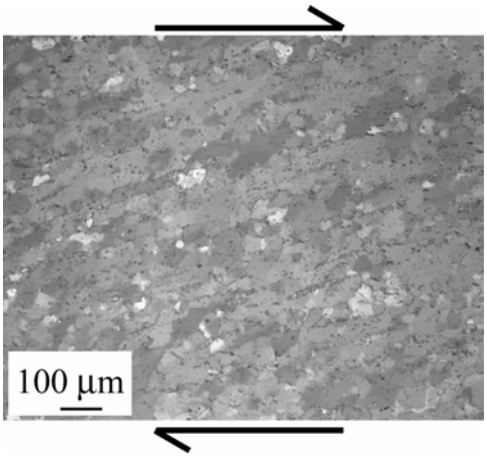

Figure 3: Micrograph of thin section of sample of Fo_{50} obtained using differential interference contrast in combined reflected and transmitted light. Grains are elongated subparallel to shear direction with γ = 3.5.

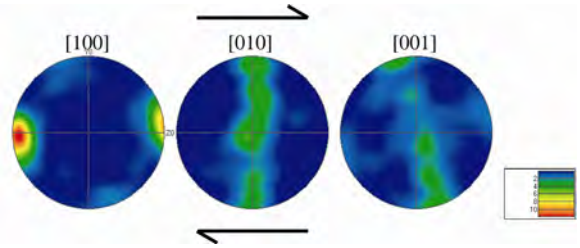

Figure 4: Pole figure for Fo_{50} sheared to γ = 3.5, shown as lower hemispheric equal-area projection. Shear plane is horizontal and shear direction is dextral.

References:

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