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Permeability and 3-Dimensional Melt Distribution in Partially Molten Rocks

Wen-lu Zhu (1), Glenn Gaetani (2), and Florian Fusseis (3)

(1) Department of Geology, University of Maryland, College Park, MD 20742, USA, wzhu@geol.umd.edu, (2) Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA, ggaetani@whoi.edu, (3) Western Australian Geothermal Centre of Excellence, University of Western Australia, Crawley, WA 6009, Australia

Quantitative knowledge of the distribution of small amounts of silicate melt in peridotite and of its influence on permeability are critical to our understanding of melt migration and segregation processes in the upper mantle, as well as interpretations of the geochemical and geophysical observations at ocean ridges. For a system containing a single solid phase of isotropic interfacial energy, chemical and mechanical equilibrium requires a constant mean curvature of solid-melt interfaces and a single dihedral angle. Under these conditions, a simple power-law relationship between permeability, grain size and melt fraction, has been derived [e.g. von Bargen and Waff, 1986]. However, microstructural observations on texturally equilibrated, partially molten rocks reveal that the melt distribution is more complex than predicted by the isotropic model. Several factors, such as non-hydrostatic stress, anisotropic interfacial energy, or the presence of a second solid phase, will alter the power-law relationship.

Better estimates for the permeability of partially molten rock require an accurate assessment of 3-dimensional melt distribution at the grain-scale. Existing studies of melt distribution, carried out on 2-D slices through experimental charges, have produced divergent models for melt distribution at small melt fractions. While some studies conclude that small amounts of melt are distributed primarily along 3-grain junctions [e.g. Wark et al., 2003], others predict an important role for melt distribution along grain boundaries at low melt fractions [e.g. Faul 1997].

Using X-ray synchrotron microtomography, we have carried out the first high quality non-destructive imaging of 3-dimensional melt distribution in experimentally equilibrated olivine-basalt aggregates [Zhu et al., 2009]. Microtomographic images of melt distribution were obtained on 1 mm cylindrical cores with melt fractions of 0.2, 0.1, and 0.02, at a spatial resolution of 0.7 microns. Textual information such as melt channel size and channel connectivity was determined using AVIZO and MATLAB. Our data indicate that as melt fraction decreases from 0.2 to 0.02, grain size increases slightly whereas melt interconnectivity decreases. Network modeling and the Lattice Boltzmann method provide a quantitative link between the macroscale transport properties and microscale melt distribtution. Incorporating our quantitative 3-D melt distribution data into these models allow us to simulate melt transport and, thereby, calculate the permeability and electrical conductivity of partially molten peridotite, especially at low melt fractions.