Mantle Flow, Melt Migration, and Seismic Anisotropy: Aligned Against the Flow

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The compositions and properties of melt are important indicators of the geochemical and geophysical evolution of our planet. Through his theoretical investigation of magnetism, Louis Néel had a major impact on our appreciation of the critical information captured by melt solidified along a mid-ocean ridge. In a much more modest effort on partially molten rocks, my colleagues and I have studied the role of small amounts of melt on the viscosity of rocks and the intimately connected effects of deformation on the distribution of the melt phase. The results of this research provide a basis for understanding ductile flow in partially molten portions of the mantle, melt migration from the source region at depth in the Earth to the surface, and physical properties such as seismic anisotropy and electrical conductivity in partially molten regions of the lower crust and upper mantle.

Deformation is often intense in regions of the mantle in which melt production is large. Over the past few years, we have investigated the deformation response of partially molten rocks under well-controlled laboratory condition, both with high-resolution creep experiments and with high-strain simple shear experiments. The viscosity of rocks in partially molten regions of the mantle will be reduced by the presence of melt but increased by drying out of the rock as water partitions from the mineral phases into the melt. However, as deformation proceeds, melt segregates and self-organizes into melt-rich channels. These melt-rich areas are not only zones of significantly lower viscosity but also interconnected networks of high-permeability paths that allow for rapid transport and extraction of melt. The melt-rich channels are oriented $\sim 20^\circ$ to the shear plane and antithetic to the shear direction, indeed, aligned against the flow. Localization of deformation into melt-rich channels also affects seismic properties in at least two ways. First, the crystallographic preferred orientation that develops in a sheared partially molten rock is quite distinct form that in a sheared fully crystalline rock; hence, the seismic properties will be distinctly different. Second, the networks of subparallel melt-rich bands influence both splitting of shear waves and attenuation of seismic waves. These two effects will have a significant influence on interpreting observations of seismic anisotropy in terms of patterns of mantle flow. As our understanding of the interplay between partial melting and deformation improves, so will our ability to provide constraints on ductile flow, melt migration, and seismic anisotropy in the mantle.