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The Importance of Mineral Physics for Understanding Mantle Dynamics and Seismic Structure

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Phase transitions have a first-order influence on the mantle, yet mantle dynamics calculations typically only include one or two major transitions despite the complexity of phase diagrams for mantle mineralogy. In our recent work, phase assemblages of mantle rocks calculated from the ratios of six oxides (CaO-FeO-MgO-Al2O3- SiO2-Na2O) by free energy minimization are used to calculate the material properties density, thermal expansivity, specific heat capacity, and seismic velocity as a function of temperature, pressure, and composition, which are incorporated into a numerical thermochemical mantle convection model in a 3-D spherical shell. The advantage of using such an approach is that thermodynamic parameters affecting dynamics and seismic velocities are included implicitly and self-consistently, obviating the need for ad hoc parameterizations. We test the sensitivity of convective behaviour and resulting mantle structure to the compositions of mid ocean ridge basalt (MORB) and harzburgite. Results indicate that thermo-chemical structures are quite sensitive to variations in MORB composition of the order 1-2% oxide fraction, particularly FeO and Al2O3. Differences occur in (i) the amount of compositional stratification around 660 km depth caused by the inversion of the MORB-harzburgite density difference between about 660 - 740 km depth, which is different in magnitude and depth extent between the different tested compositions, and (ii) in the degree of MORB segregation above the CMB, which is related to differences in the MORB-harzburgite density difference in the deep mantle. Comparing model spectra to those of seismic tomography, in all cases there is too much heterogeneity at mid lower mantle depths compared to typical seismic tomographic models, which implies that less CMB basalt segregation occurs in Earth than in the models. This probably indicates the need for better thermodynamic data for minerals at deep mantle pressures and temperatures.

Keywords: mantle convection, plate tectonics, mineral physics, numerical simulation