Mantle mixing and the persistence of geochemical reservoirs

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It has long been a goal of computational geodynamics to understand the factors controlling the rate and efficacy of mixing in the mantle; this process is fundamental to understanding the origins and characteristics of the isotopic heterogeneity observed in oceanic islands and at mid-ocean ridges. The stretching and folding common to all kinematic mixing disperses heterogeneity mixing the mantle, and leads to the overal global homogeneity exhibited in mid-ocean ridges. However, a successful model of mantle convection must also explain the long-lived heterogeneity observed on all scales in oceanic basalts and the distinct sources observed in oceanic islands. The time and spatial scales of mixing are influenced by the kinematics of flow, plate motion, viscosity variations, compositional heterogeneity, and phase transitions. Chaotic mixing is observed in time-varying 2-D flows; by contrast, the factors controlling mixing in 3-D remain poorly understood. Here, an adaptive mesh finite element code, Aspect, is used to investigate mixing by convection in a 3D layer. Aspect is based on the Deal.II library and developed and is distributed through the Computational Infrastructure for Geodynamics (CIG). Models are run at a range of Rayleigh numbers, with and without temperature-dependent viscosity, to investigate the effect of these parameters on the resulting mixing. Before any investigation of mixing, each calculation is run long enough to eliminate the transient behavior associated with the choice of initial conditions. When the model achieves a quasi-steady state, massless tracer particles are introduced to investigate and allow visualization of the mixing. The tracers are then tracked over time. The resulting tracer distributions demonstrate that stirring may be rapid on a regional scale, while heterogeneities at the global scale are retained because of isolation across long-wavelength cells. Essentially, the regions of the flow that exhibit high rates of stretching and thinning have the most important influence on mixing over the entire convection system. The tracer distributions are visualized using a variety of techniques including volume visualization with tracers to reveal the complex, anisotropic structures that develop.