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Mapping mantle complexity in 4-D geodynamical models of circulation beneath migrating mid-ocean ridges

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Melt production at mid-ocean ridges is a dominant mode of crustal production and vertical heat/mass transfer. Geodynamic models have struggled to incorporate realistic features of ridge systems, like 3-D transform offsets and migration. We present results from an innovative laboratory ridge apparatus that allows for precise and repeatable 4-D simulations of plate spreading with transform offsets and migration. The apparatus utilizes continuous belts to simulate plate spreading with three 600km wide ridge segments and up to 300km transform offsets. A stepper motor drive system allows for both axis-parallel and axis-normal migration directions. Belts are suspended above, and in contact with, a reservoir of viscous glucose syrup representing the upper mantle. High-resolution digital cameras imaging distributed clouds of neutrally buoyant tracers combined with particle image velocimetry methods allow us to map material transport and flow-induced anisotropy in high spatial-temporal resolution beneath migrating mid-ocean ridges. Experiments cover an expansive parameter space including spreading rates, migration speeds and directions, degrees of spreading asymmetry, transform offset lengths, and upper mantle viscosity conditions. Results show that the influence of migration is significant for both the spatial and temporal characteristics of shallow mantle flow. Notably, modeled mantle flow rarely follows fixed streamlines commonly reported in numerical models. Migration causes mantle pathlines (which control material transport to the melt zone under ridges) to be highly complex, often drawing in shallower fluid with significant ridge-parallel components of flow. Transform offsets, with and without migration, induce small-scale flow perturbations that make source pathways for the fluid entering the melt triangle even more complex. Empirical relationships are developed between plate parameters (spreading rate, migration vectors, etc.) and resupply flow patterns to the ridge axis. Such laws can be used to make predictions about real-world mantle flow at mid-ocean ridges and related implications for melt volume/chemistry and the geochemical, geological, and geophysical evolution of the shallow mantle. Results highlight the need to incorporate geodynamical models capable of representing 3-D geometries and migration into process models that include the expanding database of geochemical and seismic anisotropy measurements.