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Deformation, stirring and material transport in thermochemical plumes

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The distinct and diverse characteristics of the oceanic island basalts in geochemistry are generally attributed to the mixture of various mantle components in the mantle plumes. Stirring and mixing may involve: (1) the entrainment of the ambient mantle, and (2) convective mixing containing the processes those result in the chemical heterogeneities in the source region and those during the plume formation. Here we use particle trajectories and marker chains for tracking of the entrainment and material transport. We also calculate the finite time Luyaponov exponents as an indicator of deformation and stirring for a series of dynamical models of thermochemical plumes. Our results show that a substantial fraction of the surrounding mantle material at various depths can be heated and eventually entrained into the plume under certain conditions. This indicates that plume sampling the ambient mantle material on its way to the base of the lithosphere cannot be ruled out. For models with episodic pulsations or with small-scale convection due to the interaction between the thermal and compositional buoyancy forces, material in the plume and the source region can undergo strong stretching and folding. The dispersion of chemical heterogeneity is much more effective than that in the purely thermal plumes. Structures such as streaks, filaments and tendrils are found in the plumes. For models with pulsations, the edge of the secondary instability has the largest values of finite time Luyaponov exponents and acts as a transport barrier, which is similar to the frontier of the plume head. Unmixed regions are found between the maximum stretched regions caused by the injection of the secondary instabilities. These results have implications for the interpretation of the geochemical signatures of the oceanic island basalts and flood basalts.