Oscillatory vs. stagnant plumes in the Earth's lower mantle

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Mass balance considerations based on chondrites compositions as well as the observed anticorrelation between bulk sound and shear wave velocities suggest that a significant part of the deep mantle is enriched in Si and Fe, relative to the bulk mantle composition. The presence of these compositional heterogeneities may have a first order impact on the dynamics of ascending mantle plumes through their induced chemical density contrast $\Delta\rho_\chi/\rho$ at ambient temperature and at a given pressure, with respect to the surrounding mantle. By considering an assemblage of lower mantle phases (Mg,Fe)SiO_3 perovskite and (Mg,Fe)O magnesiowüstite one can show, using mineral physics data and thermodynamic considerations, that $\Delta\rho_\chi/\rho$ may significantly vary with pressure in the lower mantle (up to 200% variation), depending on the Si and Fe enrichment considered for chemically distinct material.

We therefore present a study of the coupled effects of mineralogy and pressure on the dynamics of axisymmetric thermochemical plumes in the lower mantle, using both high resolution numerical experiments and simple analytical theory.

Our results show that depending on the composition, the effect of pressure can be considerable: (1) For relatively low Si enrichment, $\Delta\rho_\chi/\rho$ is fairly constant with pressure and an oscillatory behavior of the plume head is observed, similar to previous laboratory experiments [*Davaille, 1999*] but without the need of large volume of chemically distinct material. (2) For Si-enriched compositions with respect to a reference pyrolitic mantle, the chemical density excess increases significantly with decreasing pressure implying the presence of large volume, stagnant plume heads at a level of neutral buoyancy at various possible lower mantle depths.

These results imply that, although thermochemical plumes can fully develop and rise towards the surface, their ascent may be impeded by the chemical density excess and its increase with decreasing pressure. As a consequence, these thermochemical plumes may display broad ($\sim$ 1200 km wide) negative seismic velocity anomalies in the mid-mantle which can be associated with upwellings but also with downwellings or vertically stagnant flows. The implications on heat flow budget will also be discussed.

References:

Davaille, A. Simultaneous generation of hotspots and superswells by convection in a heterogeneous planetary mantle. Nature, 402,756760, 1999.