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Dynamics of thermo-chemical mantle plumes and their influence on surface topography

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According to widely recognised models, large igneous provinces (LIPs) develop as a result of plumes ascending from the core-mantle boundary and the associated massive melting when the plume head reaches the base of the lithosphere. Most of these models include kilometer-scale topographic uplift before and during the eruption of flood basalts. On the contrary several paleogeographic and paleotectonic field studies indicate significantly smaller surface uplift during the development of many LIPs.

Recent geodynamic models show that the interaction of thermo-chemical, rather than purely thermal, plumes with the lithosphere explains observations for LIPs much better. This includes small premagmatic uplift and enormous magmatic activity even at thick cratonic lithosphere. Such thermo-chemical plumes are formed by the entrainment of dense material derived from recycled oceanic crust while the plume ascends from the D”-layer. Presence of this material reduces plume buoyancy and thus generates smaller surface uplift. However, previous studies considered neither the interaction of the thermo-chemical plume with transition zone phase boundaries nor its motion in the lower mantle. They also assume a constant density difference between peridotite and eclogite, or neglect phase transformations.

In this work we present a systematic study of the dynamics of thermo-chemical plumes in the whole mantle and their influence on dynamic topography. For that we use a two-dimensional axisymmetric finite-element model that includes 410 km and 660 km phase boundaries as well as depth-dependent density difference between pyrolite and the MORB material. We employ a modified version of the Citcom code that includes mantle compressibility, a tracer-ratio method to incorporate the two chemical components and strongly temperature- and depth-dependent viscosity.

Our study shows that thermo-chemical plumes cause a surface uplift on a scale of 150 – 1000 m during their ascent and spreading below the lithosphere. This is significantly smaller than predicted for purely thermal plumes. We show that a plume containing a too high fraction of recycled oceanic crust to rise to the lithosphere more likely ponds at a depth of 300 – 400 km than at the 660-km phase boundary. This barrier is caused by the high density contrast between eclogite and pyrolite in this region. In addition, we show that neglecting phase transformations and the depth-dependence of MORB density leads to substantial different results.