
Temporal evolution of thermochemical plumes in the Earth's mantle

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Given the characteristics of the Earth's mantle, hot thermal plumes should be an important mean of heat and mass transfer in the planet, providing an explanation for the numerous « hot spots » on the surface, characterized by important volcanism. However, the bottom of the Earth's in also probably heterogeneous. In this case, Fluid Dynamics predicts that a variety of thermochemical plumes is generated from a thermal boundary layer which is stratified in composition [1, 2], with different morphologies reflecting the temporal and spatial variation of heat and mass transfers. The behaviors of thermochemical plumes depend on their initial buoyancy ratio B_0 (Fig.1), i.e. the ratio of the stabilizing chemical buoyancy to the destabilizing thermal buoyancy at the onset of convection, and also on time (Fig.2). Because a rising plume cools along the way by thermal diffusion, a chemically composite thermal plume eventually attains a level of neutral buoyancy (i.e. B=1), at which it begins to collapse. Separation within the plume then occurs, whereby the compositionally denser material sinks back while the heated surrounding fluid keeps rising. In order to find out the maximum height of the hot thermochemical plume head in the Earth's mantle, and the reccurence time of the plume generation, we carefully investigated the experimental results obtained by quantitative visualization techniques of temperature, composition, and velocity fields (TLCs-LIF method). Scaling analysis based on [1] shows that the maximum height increases with the Rayleigh number and decreases with B (Fig.3). This put tight constraints on the maximum compositional density contrast that a plume is able to pull to the surface (Fig.4) and gives a framework to interpret the increasing body of geochemical and seismological observations.

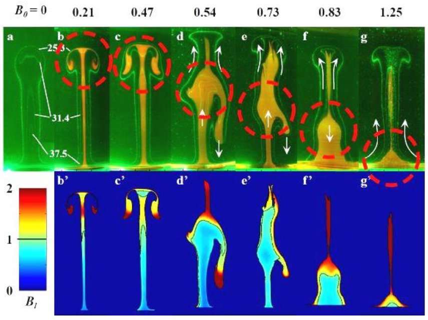

Figure 1. Snapshots showing the initial buoyancy ratio dependence (top) and the distribution of local buoyancy ratio obtained by TLCs-LIF method (modified [2]).

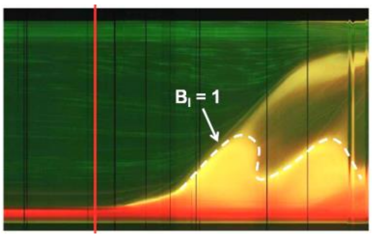

Figure 2. Spatio-temporal slice at the axis of a thermo-chemical plume (B_0=0.83). The oscillations reflect the reccurence time of the plume generation. The red line shows the onset of convection.

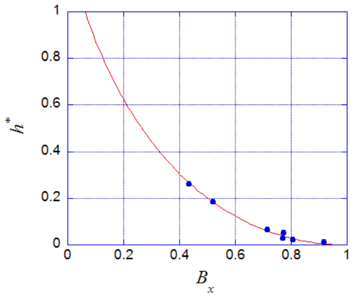

Figure 3. Maximum height h^* (= $h(t_{max})/\{\alpha g \Delta T d^4/\kappa\nu\}$) reached by a thermochemical instability as a function of B_x.

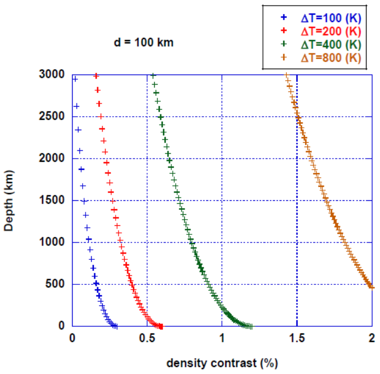

Figure 4. Maximum height reached by of a thermochemical instability in the Earth's mantle predicted by our scaling law.

References

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