12th International Workshop on Modeling of Mantle Convection
and Lithospheric Dynamics

August 20th to 25th 2011, Döllnsee Germany

Bent-shaped plumes and horizontal channel flow beneath the 660 km discontinuity

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Recent high-resolution seismic imaging of the transition zone topography beneath the Hawaiian archipelago showsstrong evidence for a 1000 to 2000 km wide hot thermal anomaly ponding beneath the 660 km boundary west of Hawaiiislands [1]. This scenario suggests that Hawaiian volcanism may not be caused by a stationary narrowplume rising from the core-mantle boundary but by hot plume material first held back beneath the 660 kmdiscontinuity and then entrained under the transition zone before coming up to the surface. Using a cylindricalmodel of mantle convection with multiple phase transitions, we investigate the dynamical conditions for obtainingthis peculiar plume morphology. Focusing on the role exerted by pressure-dependent thermodynamic and transportparameters, we show that a strong reduction of the coefficient of thermal expansion in the lower mantle and aviscosity hill at a depth of around 1800 km are needed for plumes to have enough focused buoyancy to reach and passthe 660 km depth interface. The lateral spreading of plumes near the top of the lower mantle manifests itself as achannel flow (Figure 1) whose length is controlled by the viscosity contrast due to temperature variations $\Delta\eta_T$. Forsmall values of $\Delta\eta_T$, broad and highly viscous plumes are generated that tend to pass through thetransition zone relatively unperturbed. For higher values ($100 \leq \Delta\eta_T \leq 1000$), we obtainhorizontal channel flows beneath the 660 km boundary as long as 1500 km within a timescale that resembles that of Hawaiian hotspot activity. This finding could help to explain the origin of the broad hot anomaly observed west ofHawaii. For a normal thermal anomaly of 450 K associated with a lower mantle plume, we obtain activation energiesof about 400 kJ/mol and 600 kJ/mol for $\Delta\eta_T$=100 and 1000, respectively, in good agreement with valuesbased on lower mantle mineral physics. If an increase of the thermal conductivity with depth is also included, ourmodel can predict both long channel flows beneath the 660 km discontinuity and also values of the radial velocityof local blobs sinking in the lower mantle of around 1 cm/yr, in good agreement with those inferred byvan der Meer et al. for the sinking rate of cold remnants of subducted lithosphere [2].

References

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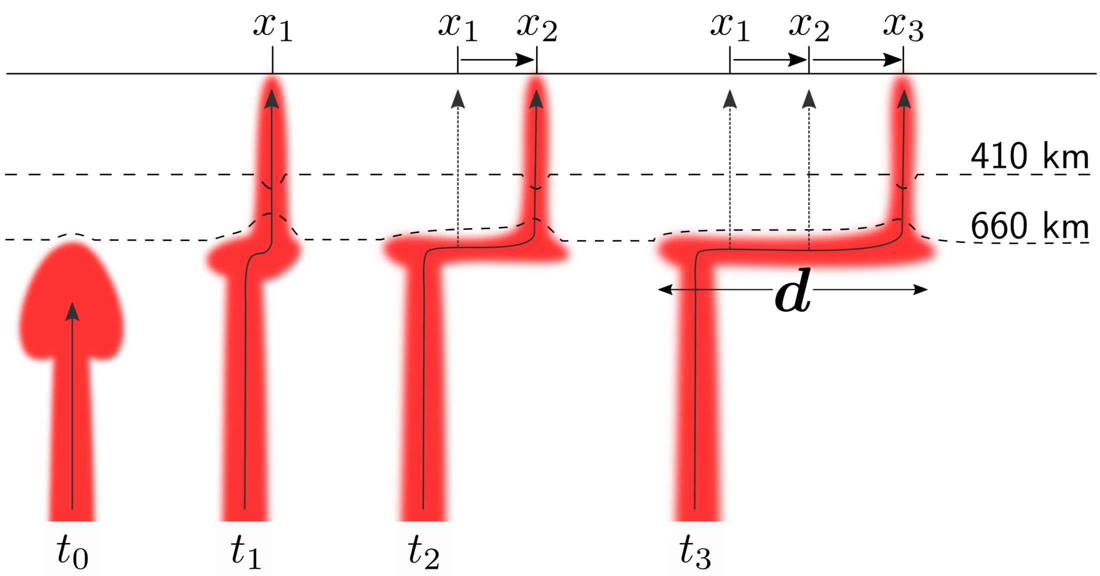

Figure 1: Schematic diagram illustrating the formation mechanism of a bent-shaped plumewith the accompanying channel flow below the transition zone. Time t_0: a highly buoyant plume reaches the top ofthe lower mantle. Time t_1: after being retarded and slightly deformed by the 660 km phase transition, the plumereaches the surface at a location x_1. Time t_2: hot material supplied from below is held back by the phasetransition and flows preferentially horizontally while the upper mantle branch of the plume is advected towards anew position x_2. Time t_3: horizontal motion beneath the transition zone continues until the tip of the plumeat the surface reaches the position x_3 and the channel flow attains its maximal horizontal length d.