Convection models of the heterogeneous Iceland plume

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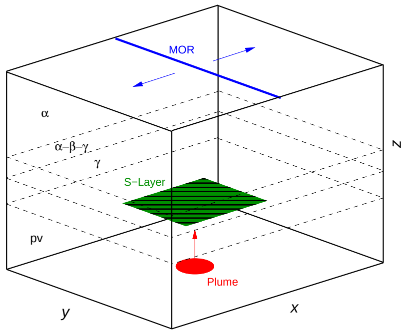
Model design

A preliminary set of tests of the dynamics of a mantle heterogeneity initially located on top of the 660 km discontinuity hit and possibly dragged along by a plume from the lower mantle is presented. The motivation of this setting is the proposal that such a layer has been located beneath today's Iceland and has been carried along with the plume, resulting in a distinct zoned pattern of chemical anomalies in the Iceland area (*e.g.* Thirlwall, 1995; Kempton et al., 2000; Murton et al., 2002).

The models consist of a 3000 km ×1200 km ×1000 km (216 × 86 × 150 points) box. The equations of convection, energy conservation and diffusion-free chemical advection are solved to model the ascent of a plume through the uppermost lower and the upper mantle and its spreading beneath a MOR. Seafloor spreading is introduced as a kinematic boundary condition at the top of the model box, and the phase transitions of olivine are included in a simplified way as functions of p and T. A plume with a maximum temperature anomaly of 220 K and a radius of 300 km at the model bottom flows into the box through a circular area. Its viscosity is reduced due to an elevated water content of 500 ppm, whereas the reference mantle contains 142 ppm; the rheology is generally described as a function of depth, temperature, and water content of the solid rock. The layer-type anomalies ("S-layers") in the different models are prescribed using a compositional field to which certain properties are attached, and, optionally, by a thermal variation.

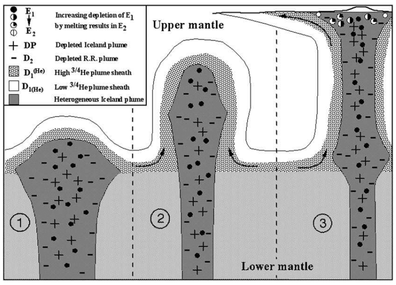


⟵ **Scheme of initial condition of models (not to scale)**

The original sheath model

The pattern of chemical anomalies in the larger Iceland area has led to the idea that the plume picks up MORB-like material residing at the bottom of the transition zone when it ascends into the upper mantle (Thirlwall, 1995; Kempton et al., 2000). This material would wrap around the plume as a "sheath", and the resulting pattern of chemical anomalies observed at the surface would consist of sheath components mostly in the remote, down-ridge realms and genuine lower-mantle plume components in the central parts corresponding to Iceland.

Vertical cross section through the sheath model (from Murton et al., 2002) ⟶



The feasibility of this model depends, among other factors, on the ability of the plume to cross the endothermic phase boundary *and* lift a body with physical properties different from the background mantle and likely to resist ascent: if the sheath is MORB-like, it is expected to consist at least partially of eclogite, which has a greater density than peridotite, and it might also be cooler and more viscous than the background mantle. This adds to the difficulty for a plume to penetrate the perovskite–ringwoodite transition.

Under which conditions can a plume rise into the upper mantle and take such a body with it? In the preliminary models shown here, three variables of the S-layer affecting its mobility – density, viscosity, and temperature – are varied:

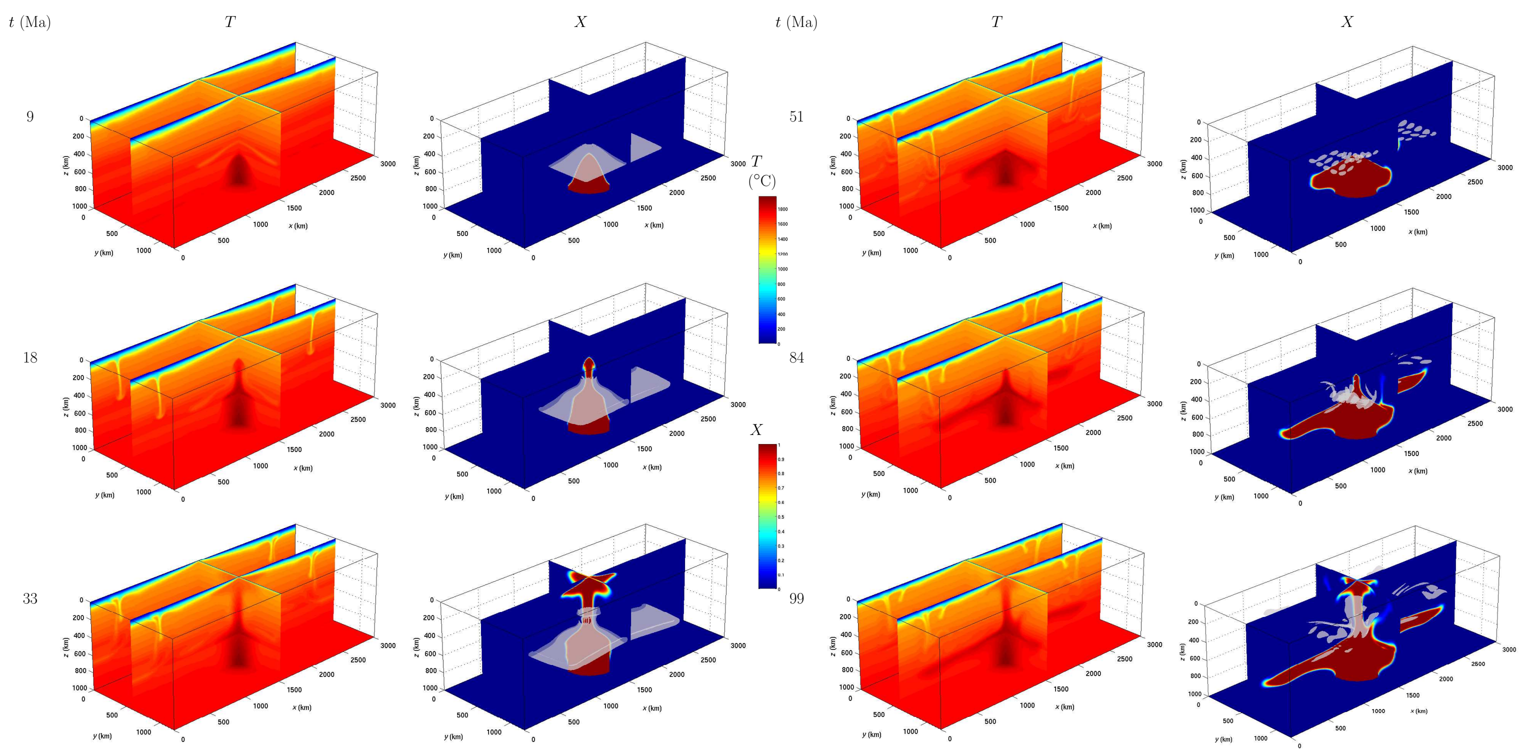
structure	coherent				non-coherent		
$\Delta\varrho$ (kg/m³)	0	0	0	15	0	0	15
$\eta/\eta_{\rm ref}$	1	3	1	1	1	3	1
$\Delta T_{\rm S}$ (K)	0	0	−150	0	−150	−150	−150

Results

The figure below shows slices of the temperature and composition fields of two models, each of them typical for one endmember case of dynamical behaviour: in the left block, the S-layer is distinguished from normal mantle only by a contiguous thermal anomaly, which affects density and viscosity indirectly, but slightly; in the right block, the S-layer is not contiguous, but an ensemble of small cold parcels, which have a compositionally caused higher density than the respective background. In the latter case, the plume first stalls and spreads below the 660, and the S-layer is more strongly deformed when the plume rises through the upper mantle.

Coherent S-layer, $\Delta\varrho = 0\,{\rm kg/m^3}$, $\eta/\eta_{\rm ref} = 1$, $\Delta T_{\rm S} = -150\,{\rm K}$

Non-coherent S-layer, $\Delta\varrho = 15\,{\rm kg/m^3}$, $\eta/\eta_{\rm ref} = 1$, $\Delta T_{\rm S} = -150\,{\rm K}$



Preliminary conclusions

1. A dense S-layer can retard the rise of a plume through the 660 km boundary.
2. Material from the S-layer does not seem to rise easily together with the plume, and might lag behind.
3. The viscosity of the S-layer was not found to have a profound effect thus far.

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References

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