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Three-Dimensional Plume Patterns Rising from Subducting Slabs

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In a previous set of thermo-chemical numerical experiments, we discover three types of three-dimensional (3-D) plume patterns (finger/mushroom-like, normal trench ridge-like, and wave-like plumes) that can develop above subducting slabs.

The physics of plume-pattern formation however remains insufficiently understood. Therefore, we here concentrate on a simplified mechanical setup similar to the layout atop the subducting slab, that is, higher viscous and denser asthenosphere initially overlying lower viscous and a low-density hydrated mantle. The aim of these experiments is to obtain a better insight in the underlying mechanical processes and to derive scaling laws that distinguish various modes of plume formation.

We gradually test the influence of different parameters (such as the thickness of the hydrated mantle, the dip angle of the slab, and the viscosity contrast between hydrated and surrounding mantle) on the development of Rayleigh-Taylor (RT) instabilities above the slab. We could conclude that: 1) A thinner hydrated mantle layer results in multiple 3-D finger-like plumes; 2) For increasing the dip angles, the hydrated mantle moves upwards along the slab to form trench-normal ridge-like structures, and plumes develop atop the sheet-like/roll-like walls at later stages to form 3-D structures. The larger the dip angle of the slab, the faster the positively buoyant hydrated mantle moves upwards along the slab; 3) A reduced viscosity contrast between hydrated and surrounding mantle favors a 3D diapiric plume mode; 4) An imposed shear velocity between the hydrated and surrounding mantle favors the formation of linear wall-like plumes and asymmetric plume heads. 5) A heterogeneous distribution of hydrated mantle favors wave-like plumes that sometimes form zig-zag patterns.

In addition, we demonstrate that a linear stability analysis for a three-layered RT model gives predictions that are consistent with numerical results.