

The initiation of subduction by mantle plumes - a numerical study.

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Subduction is commonly considered as a purely convergent process with external forcing. In an equilibrated environment, facilitating and triggering influences are needed to establish a self-sustaining perturbation, a matter addressed by recent numerical studies (e.g. Regenauer-Lieb et al. 2001; Hall et al. 2003). In this work, we show the theoretical possibility to induce subduction by an impinging mantle plume without external convergence. Plumes may both rupture and isostatically displace lithosphere downwards, providing the means to initiate subduction.

In order to confirm this possibility, we performed coupled 2-D petrological-thermomechanical modeling of plume-lithosphere interaction experiments based on finite differences and marker-in-cell techniques, accounting for slab dehydration reactions, water propagation and melting. While it might be counterintuitive to relate first-order point-shaped plumes and distinctly elongated subduction structures in this way, geodynamical studies (e.g. Tackley et al. 1999; Tackley 2000) have shown the stability of sheet-like plumes.

Examined numerical models relate the fully developing subduction of young oceanic lithosphere to its age and to plume size. The influence of composition and temperature of the plume on one and the brittle strength of the lithosphere on the other hand is found to be of the similar order of magnitude, while presence and interactions of fluids might be of even bigger importance. The observed evolution of such coupled systems exhibits stages from plume ascent, sublithospheric ballooning, distal underplating, proto-slab slicing over subsequent spreading of the permeated melt wedge to an isostatic response of loaded proto-slabs with finally downward movement (Fig 1.)

Depending on parameterization, this initial movement remains self-sustaining or smoothly dies out, whereas critical influence can be ascribed to fluid release and uprise. In detail, stable, retreating subduction (two-sided) shows a real disruption of lithosphere, while fluid-free modes can be approximated as narrow lithospheric folding plunging into the mantle; in addition, when initial parameters are chosen close to criticality, subduction displays an asymmetric pattern. However, not only systems with too low ratios of lithosphere age and plume size are found to fail subduction : for higher ratios the existence of an overcritical regime with slab fractionation and lithospheric buckling evolved in simulation.

Plume impingement has shown its theoretical potential to cause subsequent subduction, in overcoming the cohesion of lithosphere and exciting an initial shift. Stability of this perturbation depends on magnitude of first excitation and on the presence of volatile and reactant fluids. From the model to an assumable application, young Archean lithosphere may have subducted after being hit by wet mantle plumes in a tectonic mode more similar to modern plate tectonics. Another, dominant mode (Griffin et al. 2003) might be represented by large overcritical plumes hampering subduction.

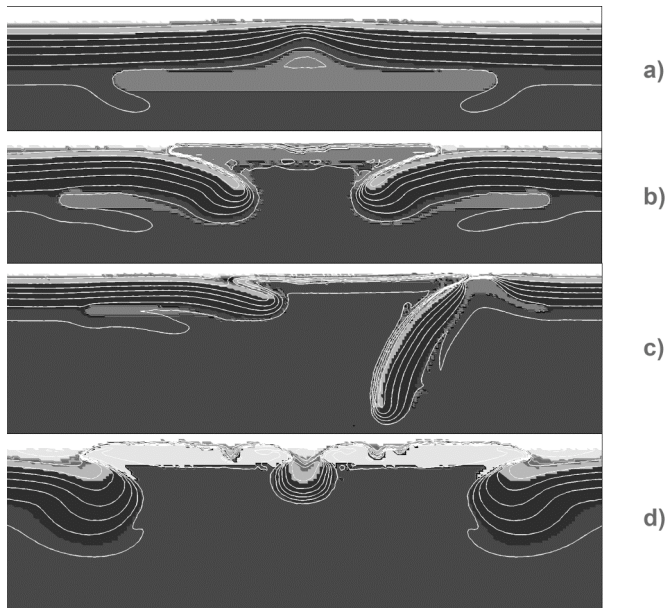


Figure 1. Development stages of subduction following plume impingement. Stable cases: After ballooning beneath the lithosphere, a wedge of plume material rises up (a), cuts the proto-slabs, spreads over them and displaces them downwards (b). Critical cases: subduction develops asymmetrically and may stop after neck-off (c). Overcriticality: plume material “burns through”, fragmenting or resorbing lithosphere (d). Plumes (a) - (c) of hydrated mantle, (d) of felsic composition.

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