Mantle plume-slab interaction: Insights from numerical models

Investigating the effect of rising plumes on subducting slabs

M. Baes, *Institute of Geologie, Leibniz Hannover University and GFZ Potsdam*

In Short

- Numerical modeling of plume-slab interaction
- Investigation of key factors controlling the possible deformation responses caused by plume-slab interaction
- Explore the effect of rising plumes on subducting and trench retreating rates

Plume-lithosphere interaction has been investigated in various studies from different perspectives including observations (e.g.,[1–3]) and modeling (e.g., [4–9]). Mantle plumes are able to produce linear volcanic chains, plateaus, large igneous provinces and continental flood basalts on the Earth. Impingement of a mantle plume on an oceanic or continental lithosphere have been subject of several previous studies (e.g., [4–12]. However, interaction of mantle plumes with subducting slabs has recieved less attention, specially from modelling point of view. [13] investigated the geological and geophysical evidence of Yellowstone plume. They indicated that plume which has produced the Yellowstone hotspot track initiated to rise from at least 1,000 km depth at 17 Ma. Interaction of this plume with lithosphere led to the widespread volcanism, with eruptions of flood basalts and rhyolite. Before reaching lithosphere, the rising plume head interacted the east-dipping Juan de Fuca slab and was deflected 250 km to the west. This resulted in slab break-off and the rapid hotspot movement of 62 km/Myr from 17 to 10 Ma. Figure 1a shows the scenario of [13] for Yellowstone plume schematically.

[14], using 3d anisotropic tomography images and 3d numerical models, studied the effect of Samoan plume on Tonga slab in Southwestern Pacific. They indicated that the interaction of Tonga slab with the Samoan plume led to the slab stagnation at 660 km and fast trench retreat. According to this study, Samoan plume originated from a mega ULVZ (Ultra Low Velocity Zone) at the core-mantle boundary and rose towards surface through the whole mantle (Figure 1b1). The plume, in its way towards the surface, interacted with the Tonga slab at the transition zone (Figure 1b2). This collision led to slab stagnation and buckling at transition zone which was followed by fast slab retreat and migration of plume materials into the mantle wedge (Figure 1b3).

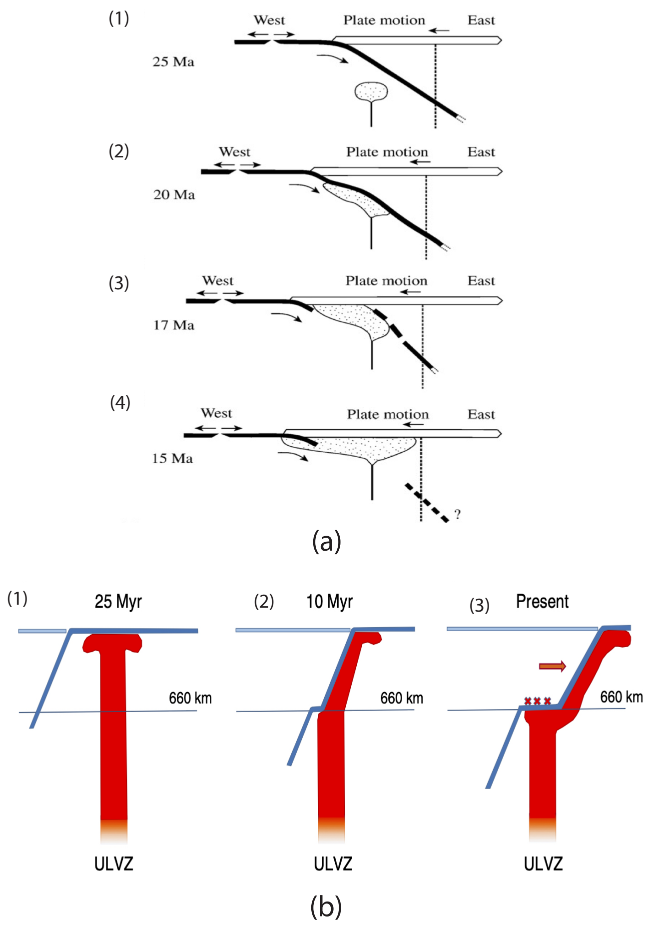

Figure 1: *Two different scenarios proposed for plume-slab interaction for (b) Yellowstone region (figure adapted from [13]) and (c) Tonga subduction (figure adapted from [14]).*

As explained above, different interpretations and scenarios have been proposed for collision of a plume with a subducting slab. In this study, we aim to investigate the possible responses of slab and plume to their interaction under different conditions like different slab ages, slab lengths and plume buoyancies. To this aim, we use I3ELVIS finite difference code to setup 3d numerical models. Our preliminary 3d model setup is shown in Figure 2. The model has the dimensions of 1230 km* 592 km* 684 km which includes a 20 km sticky-air, an old oceanic lithosphere, a younger oceanic lithosphere, a weak zone separating two oceanic plates and asthenosphere till depth of 684 km (Figure 2). The model contains more than 10 million nodes and 505 million markers. Here, our goal is to investigate plume-slab interaction using 3d numerical models to address the following questions:
- How a rising plume can affect the subducting slab?

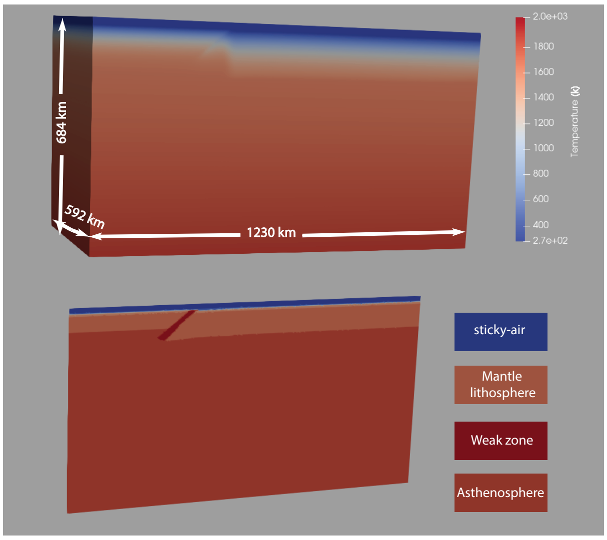

Figure 2: *Fig. 2: Initial setup of 3d numerical model. The upper panel shows the temperature field and the lower panel illustrates the different layers of the model along a cross-section cutting the middle of model.*

Whether interaction of a mantle plume with a subducting slab leads to slab break-off or subduction continues? Are the trench-retreat and/or subducting rates affected by slab-plume interaction?

Answering these questions will advance our knowledge about mantle plumes and their roles in plate tectonics.

WWW

More Information

[1] S. A. Whattam, R. J. Stern, *Geosphere* **27**, 38-63 (2015).

[2] R. J. Stern, T. A. Dumitru, *Gondwana Research* **15**, 659-681 (2019).

[3] L. Gao, S. Liu, B. Zhang, G. Sun, Y. Hu, R. Guo, *Tectonics* **38**, 1694-1717 (2019).

[4] K. Ueda, T. Gerya, S. V. Sobolev, *Physics of the Earth and Planetary Interiors* **171**, 296-312 (2008).

[5] T. Gerya, R. J. Stern, M. Baes,S. V. Sobolev, S. A. Whattam, *Nature* **527**, 221-225 (2015).

[6] M. Baes, T. Gerya, S. V. Sobolev, *Earth Planet. Sci. Lett.* **453**, 193-203 (2016).

[7] M. Baes, S. V., Sobolev, T. Gerya, S. Brune, *Geochemistry,Geophysics, Geosystems* **21**, https://doi.org/10.1029/2019GC008663 (2020a).

[8] M. Baes, S. V., Sobolev, T. Gerya, S. Brune, *Geochemistry,Geophysics, Geosystems* **21**, https://doi.org/10.1029/2020GC009119 (2020b).

[9] M. Baes, S. V., Sobolev, T. Gerya, S. Brune, *Gondwana research* **98**, 277-288 (2021).

[10] S. Cloetingh, A., Koptev, I, Kovacs,T. Gerya, A. Beniest, E., Willingshofer, et al., *Geochemistry,Geophysics, Geosystems* **22**, https://doi.org/10.1029/2020GC009482 (2021).

[11] E. Burov, S. Cloetingh, *Geophys. J. Int.* **178**, 1691-1722 (2009).

[12] E. Burov, S. Cloetingh, *Geophys. Res. Lett.* **37**, L03309. http://dx.doi.org/10.1029/2009GL041535 (2010).

[13] K. L. Pierce, L. A. Morgen, *Nature Communications* **188**, 1-25 (2009).

[14] S-J. Chang, A. M. G. Ferreria, M. Faccenda, *Journal of Volcanology and Geothermal Research* **7**, doi: 10.1038/ncomms10799 (2016).

Project Partners

T. Gerya, Department of Earth Sciences, Institute of Geophysics, ETH, Zureich