GFZ Helmholtz Centre Potsdam

Plume-induced subduction initiation: single- or multi-slab subduction?

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Introduction

Previous modeling studies (Baes et al., 2016; Gerya et al., 2015; Ueda et al., 2008) showed that interaction of a buoyant mantle plume with lithosphere can lead to initiation of multi-slab or single-slab subduction zones. However, they did not explore the controlling factors in development of the single- and multi-slab subduction zones.

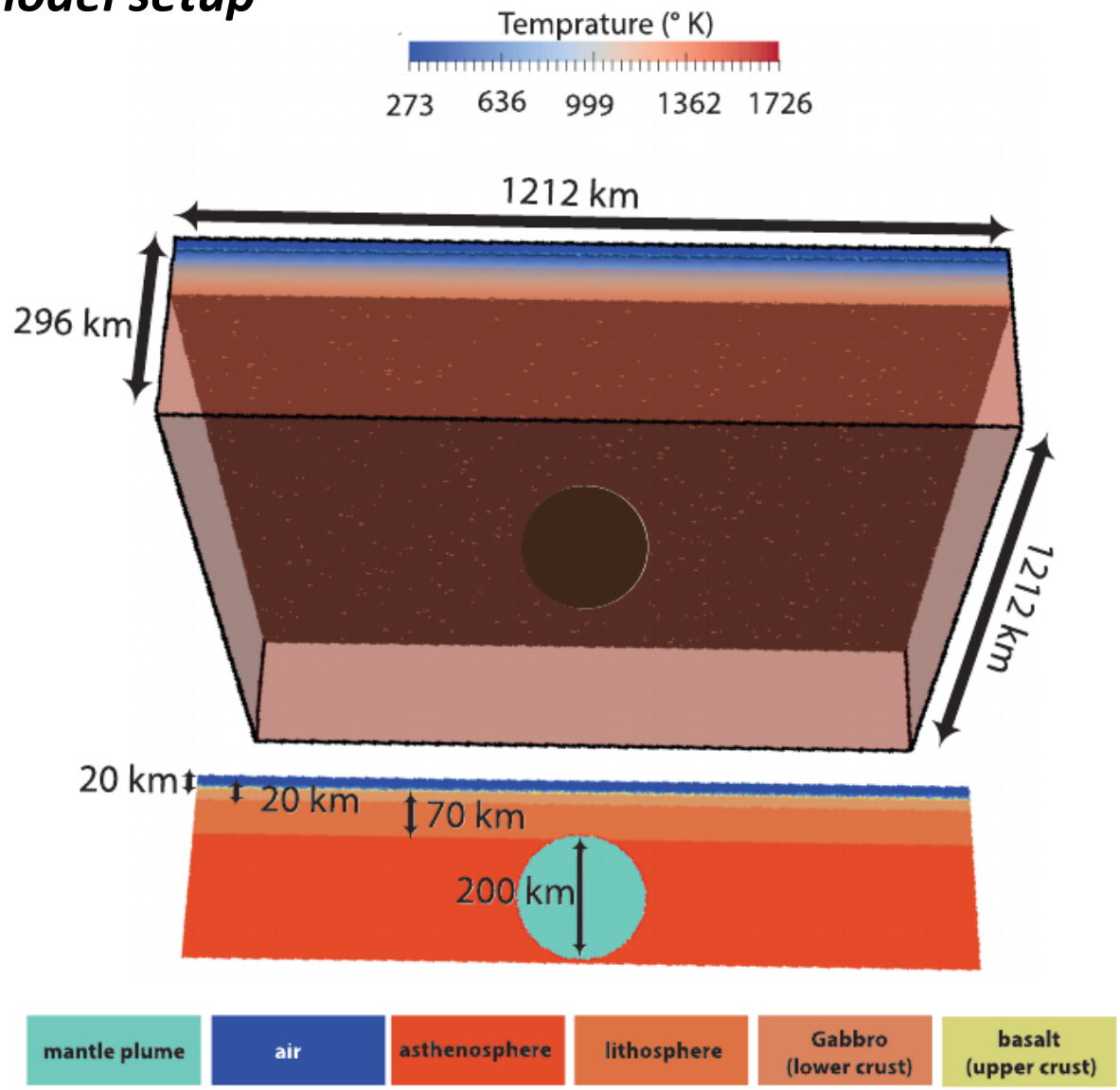
The aim of this study is to address the following questions:

- **Which lithospheric parameters play key roles in defining either single-slab or multi-slab subduction initiation?**
- **what is the impact of regional extension on plume-lithosphere interaction?**

We use the code I3ELVIS to setup numerical experiments to investigate plume-induced subduction initiation. Our models are 3-d visco-plastic thermo-mechanical experiments.

Numerical models

Initial model setup

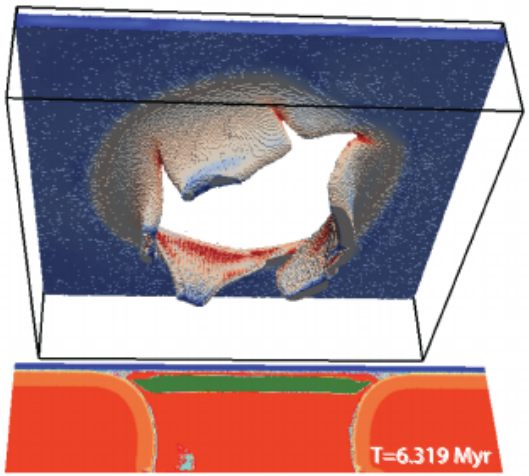


Baes et al., 2020

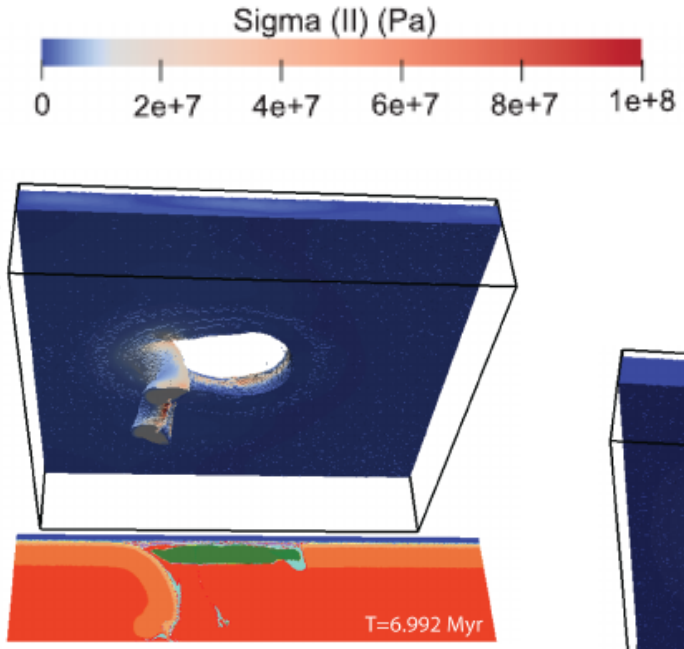
Numerical models

Effect of Crustal Thickness

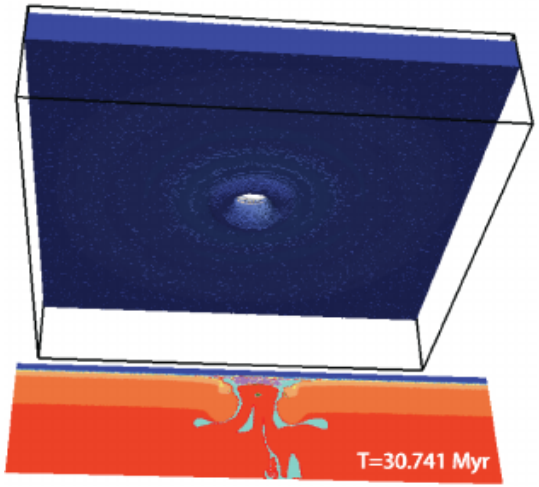
Models with different thickness of the crust and oceanic lithospheric ages show following three responses:



multi-slab subduction initiation



single-slab subduction initiation



plateau formation without subduction initiation

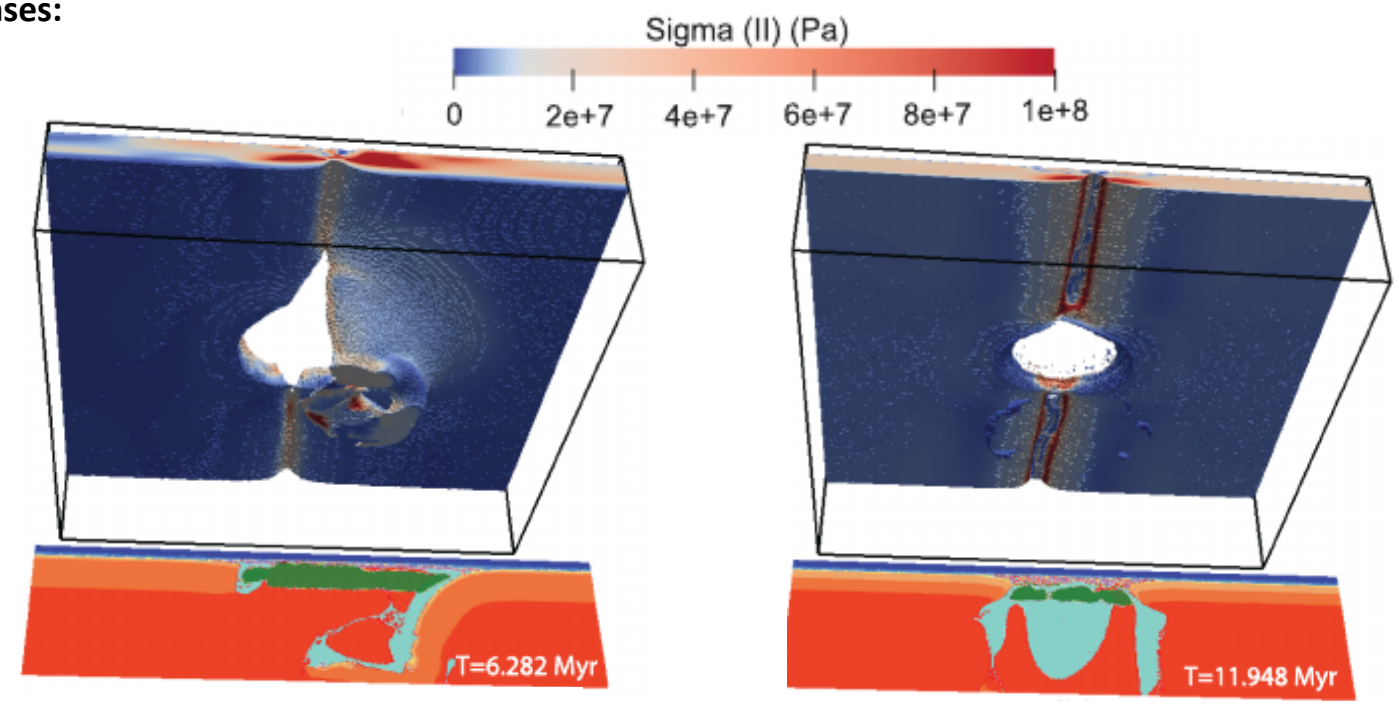
Air	Upper crust	Lower crust
Lithosphere	Asthenosphere	Plume
Volcanic crust	Molten volcanic crust	Molten mantle

Baes et al., 2020

Numerical models

Effect of Extension Rate

Models with different extension rates (05 and 1 cm/yr) and oceanic lithospheric ages show following two responses:



single-slab subduction initiation

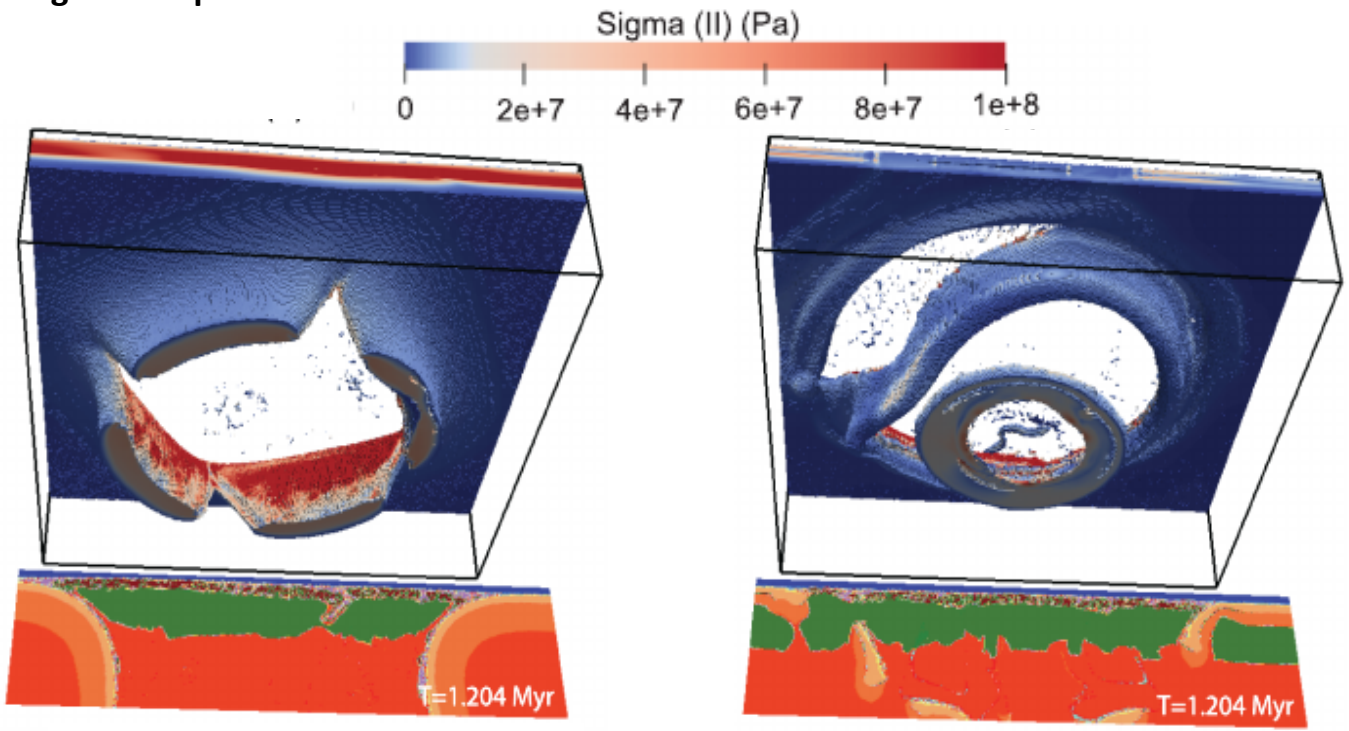
plateau formation without subduction initiation

Baes et al., 2020

Numerical models

Effect of Mantle Temperature

Models with 200 K higher mantle temperature (representing early Earth) and different lithospheric ages show following two responses:



multi-slab subduction initiation

episodic short-lived circular subduction initiation

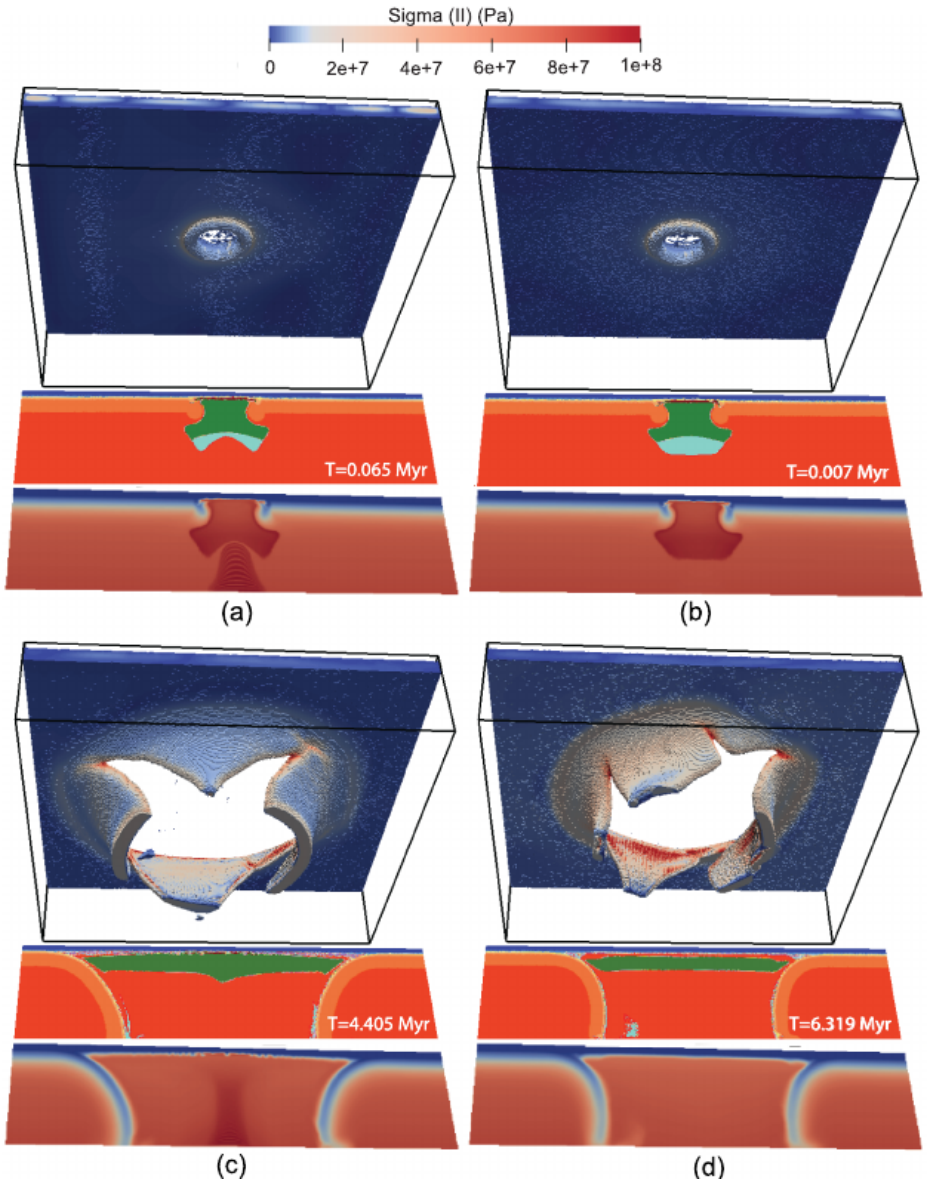
Air	Upper crust	Lower crust
Lithosphere	Asthenosphere	Plume
Volcanic crust	Molten volcanic crust	Molten mantle

Baes et al., 2020

Numerical models

Effect of Mantle Plume with a Tail

(a and c): Mantle plume with a tail
(b and d): Mantle plume without a tail

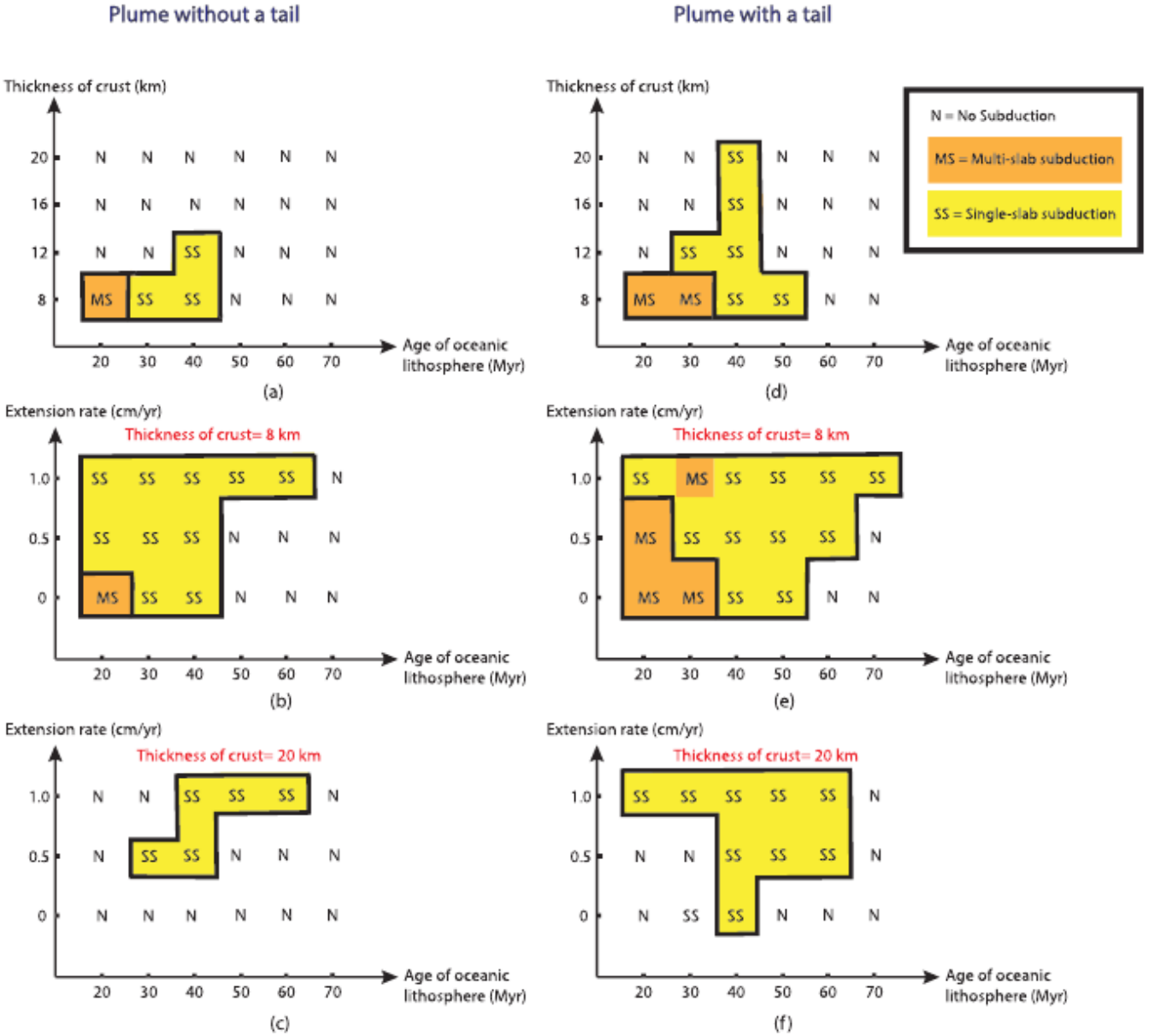


Air	Upper crust	Lower crust
Lithosphere	Asthenosphere	Plume
Volcanic crust	Molten volcanic crust	Molten mantle

Baes et al., 2020

Numerical models

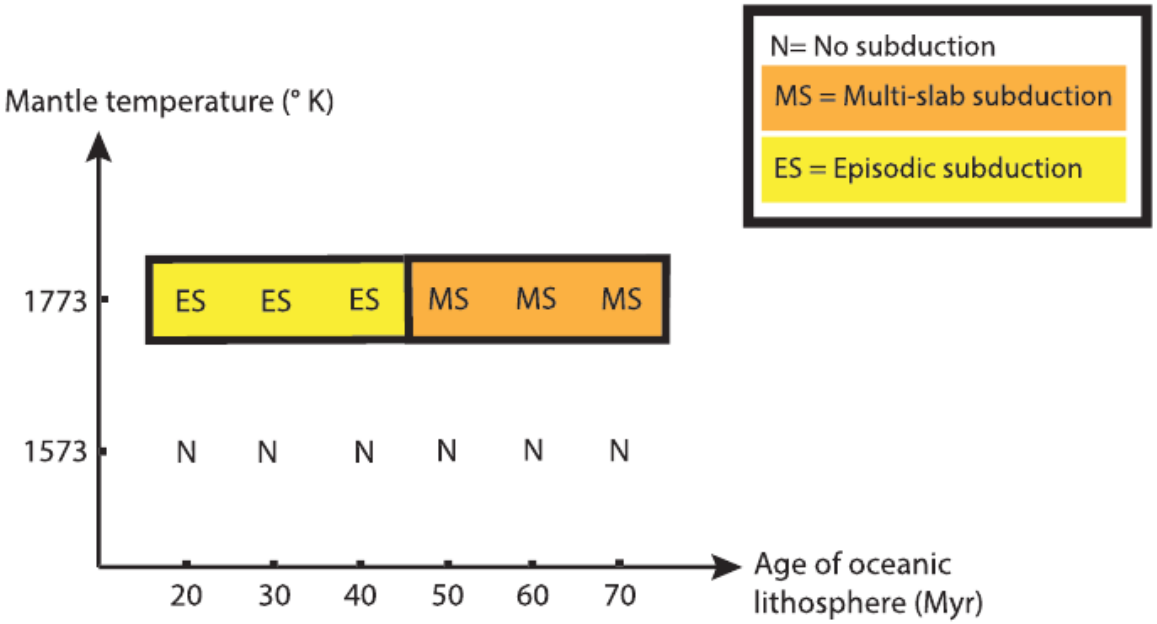
Summary of the results



Baes et al., 2020

Numerical models

Summary of the results



Baes et al., 2020

Applications

Application for the Early Earth

- **Plume-induced subduction initiation in the hot early Earth with thick crust was quite possible. This is in contrast to present day where interaction of a plume with a lithosphere containing a thick plateau unlikely leads to subduction initiation.**
- **Plume-lithosphere interaction in Archean times could result in either episodic and short-lived (young lithosphere) or multi-slab retreating (old lithosphere) subduction initiation, but not single-slab subduction zones, which are common features on modern Earth.**

Application for Caribbean

Numerical model results suggest that in order to initiate single-slab subduction in Caribbean region plume might arrived either beneath a plateau, which was under extension, or beneath a lithosphere with crustal thickness of 8 km . The lithospheric extension some 100 Ma in Caribbean could be related to the extension in the back-arc region of the west dipping Puerto Rico/Lesser Antilles subduction zone.

Baes et al., 2020

Conclusions

- ***Deformation regimes following arrival of a mantle plume beneath lithosphere depends on several parameters such as age of oceanic lithosphere, thickness of the crust, extension rate, and mantle temperature.***
- ***Plume-lithosphere interaction in present day Earth can result in three different deformation regimes: (a) multi-slab subduction initiation, (b) single-slab subduction initiation, and (c) plateau formation without subduction initiation.***
- ***In the early Earth (in Archean times) plume-lithosphere interaction could lead to formation of either multi-slab subduction zones or episodic short-lived circular subduction.***
- ***In the early Earth multi-slab subduction could be developed only if a plume interacted with an old oceanic lithosphere. Contrarily, in present-day Earth, multi-slab subduction zones can be initiated only if a plume hits a relatively young oceanic lithosphere.***
- ***Extension eases subduction initiation caused by plume-lithosphere interaction.***
- ***Plume-induced subduction initiation is facilitated if the plume has a tail.***
- ***Subduction initiation of an old oceanic lithosphere with a thick plateau is possible only if the lithosphere is subjected to an extensional regime.***
- ***We suggest that single-slab subduction in the western Caribbean was formed due to either plume-plateau interaction in the back-arc extensional regime of the west dipping Puerto Rico/Lesser Antilles subduction zone or arrival of a mantle plume beneath a lithosphere with typical crustal thickness of 8 km.***

Baes et al., 2020

References

- **Baes, M., Sobolev, S. V., Gerya, T. V., & Brune, S. (2020). Plume-inducedsubduction initiation: Single-slab ormulti-slab subduction?. Geochemistry,Geophysics, Geosystems, 21, e2019GC008663. https://doi.org/10.1029/2019GC008663**

- **Baes, M., Gerya, T. V., & Sobolev, S. V. (2016). 3-D thermo-mechanical modeling of plume-induced subduction initiation. Earth and Planetary Science Letters, 453, 193–203.**

- **Gerya, T. V., Stern, R. J., Baes, M., Sobolev, S. V., & Whattam, S. A. (2015). Plume-induced subduction initiation triggered Plate Tectonicson Earth. Nature, 527(7577), 221–225. https://doi.org/10.1038/nature15752**

- **Ueda, K., Gerya, T. V., & Sobolev, S. V. (2008). Subduction initiation by thermal–chemical plumes: Numerical studies. Physics of the Earthand Planetary Interiors, 171(1), 296–312.**