References

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Modeling subducted lithosphere fragments interacting with mantle plumes on Venus

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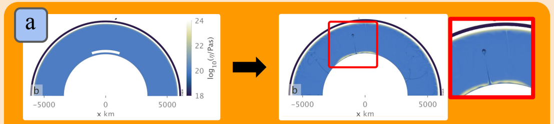
Model description

We explore how a descending fragment of the brittle lithosphere might interact with mantle convection on Venus if there was a modest temperature gradient across the core-mantle boundary (CMB), producing mantle plumes[4].

An analog two-dimensional Venus mantle is created in a half-annulus geometry using geodynamic code StagYY[5]. The mantle is modeled as a temperature-dependent, viscous fluid (10^{18} - 10^{24} Pa·s), and the equations of conservation of mass, momentum and energy (Stokes equations) are solved over time.



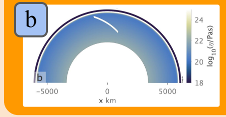


Fig. 1: (a) Initially, a 200 km elevated cold slab was modelled in a 1700 K mantle with no depth dependent viscosity and a ΔT_{CMB} of 300 K. (b) The current model initiates an elevated tilted slab and has depth-dependent viscosity.

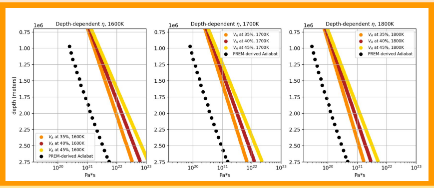


Fig. 2: To incorporate depth-dependent viscosity, the PREM pressure for Earth, and the mantle potential temperature (T_m) at the upper/lower mantle boundary was used to approximate the depth-dependent viscosity on Venus. We ran nine models using three different ratios (35-45%) of the **compressible** activation volume [V_A=1e-6] for our incompressible, Boussinesq model for three values of T_m. The depth-viscosity relationship is most similar (most parallel) to the 40% V_A, and thus is the most appropriate viscosity gradient for the reference and slab models.

Reference models

In the suite of reference models with mantle potential temperature T_m= [1600, 1700, 1800] K, and ΔT_{CMB}=[100, 200, 300, 400] K , we explore the lower limit of the temperature gradient across the CMB which produces rooted plumes in a Venusian mantle. While a 100 K jump at the CMB hardly generates a plume with a clear head and conduit, ΔT_{CMB} values of 200 K or more generate distinctive plume features.

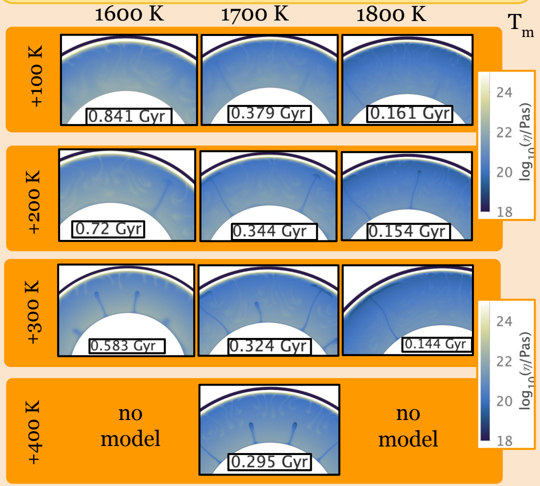


Fig. 3: The viscosity fields for the suite of reference models showing the scale of mantle plumes in 10 different temperature regimes. Notably, all models with CMB temperature jump $\Delta T \geq 200$ K produces plumes with a distinguishable head and conduit. On average, 4-7 plumes form in each model with rise-times ranging from 10-100 Ma and total lifetimes upwards of 200 Ma.

Models with slab fragment

A cold, tilted slab of uniform cold temperature (1000 K) is placed one-third of the mantle thickness deep, and allowed to freely descend to the CMB as a thermal boundary layer forms there. The thickness of the slab was varied between 150 and 300 km in intervals of 50 km, and the maximum viscosity of the slab is varied (10^{23} Pa·s, 10^{24} Pa·s, and 10^{25} Pa·s) to allow for different deformabilities of the slab.

In the presence of a subducting fragment of lithosphere, plume formation is suppressed, and the size and longevity of the mantle plume eventually forming underneath it is affected by the thickness and deformability of the slab.

Fig. 4: This 1700 (+300) K model is characteristic of all other models ran with a cold slab: the formation of plumes under it is suppressed, and the edges root two early-forming plumes.

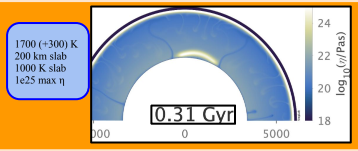


Fig. 5: In the 1700 (+400) K model, the thermal boundary grows at a fast enough rate to trap a thermal instability under the slab, which builds up and is released.

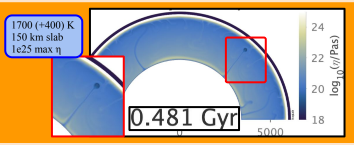
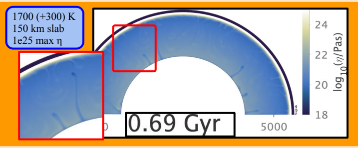


Fig. 6: After the slab suppresses plumes and it dissipates fully, plumes with smaller heads grow from the CMB in greater density than the reference model.



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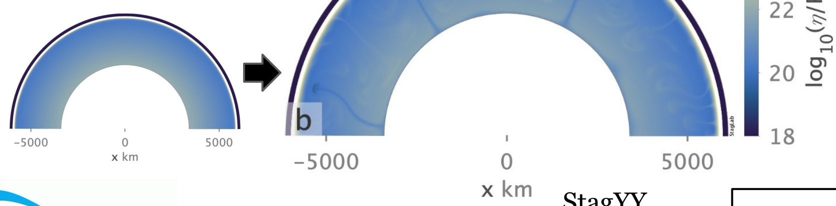
1. How small of a temperature difference across the core-mantle boundary can generate a plume on Venus?

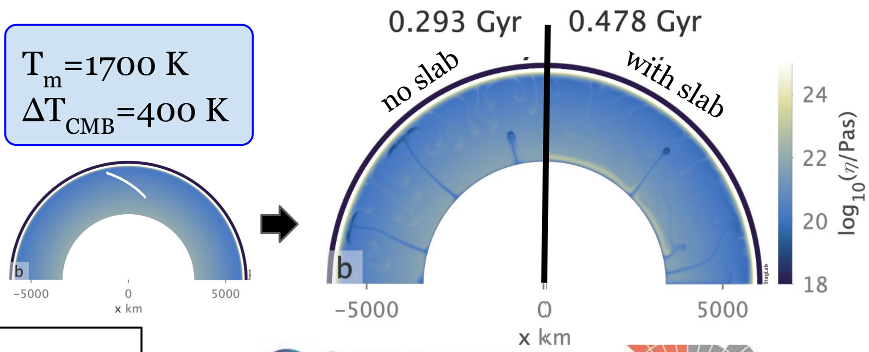
T_m=1700 K
ΔT_{CMB}=200 K



StagYY

2. How might a subducted fragment of lithosphere affect the formation and evolution of these plumes?

T_m=1700 K
ΔT_{CMB}=400 K



Modelled using StagYY (Tackley, 2020)