Modeling Rollback Subduction Dynamics on Venus

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Introduction

The relatively young surface age of Venus (250-750 Ma) has been suggested to be the result of one or more global catastrophic resurfacing events. However, *King* [2018] concluded that the center of mass - center of figure (CM-CF) offset observations for Venus are not compatible with a global overturn event. Regional-scale rollback subduction events are believed to have occurred on Venus, and lithospheric flexure and topography at coronae are thought to be signatures of these events (Sandwell and Schubert, 1992). *Schubert and Sandwell* [1995] noted a strong correlation between the possible subduction sites of Venus and regions of extension and rifting that occur along chasmata systems (Fig. 1).

In this study, we examined how density-driven lithospheric instabilities can result in regional-scale subduction events on Venus. We model a scenario of heterogeneously-thick lithosphere (Fig. 2), which could represent a rift zone or region magmatically weakened by a thermal upwelling. We aimed to determine the crust and mantle conditions conducive to subduction on Venus.

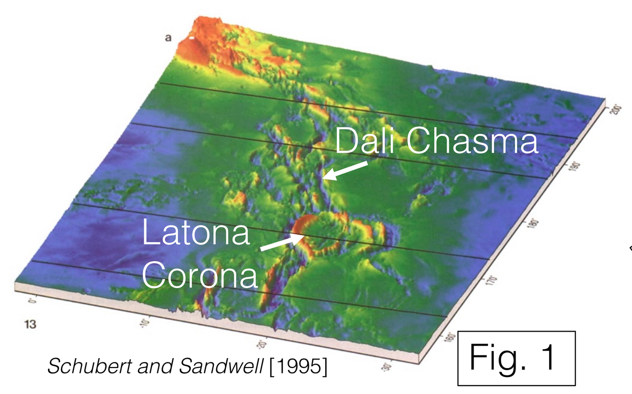

Fig. 1

Model Setup

-2D spherical annulus numerical models using StagYY (Tackley, 2008)
-Parameter space:
- Lithosphere thickness, $H_{lith\text{-}max}$ = [200, 250, 300 km]
- Maximum viscosity, η_{max} = [10^{23}, 10^{24}, 10^{25} Pa*s]
- Compositional buoyancy of crust (i.e. $B_{crust} = \rho_{0,crust} - \rho_{0,mantle}$), B_{crust} = [-175, -265, -300, -350, 400 kg/m^3]

-Post-processing and visualization done using StagLab (Crameri, 2018)

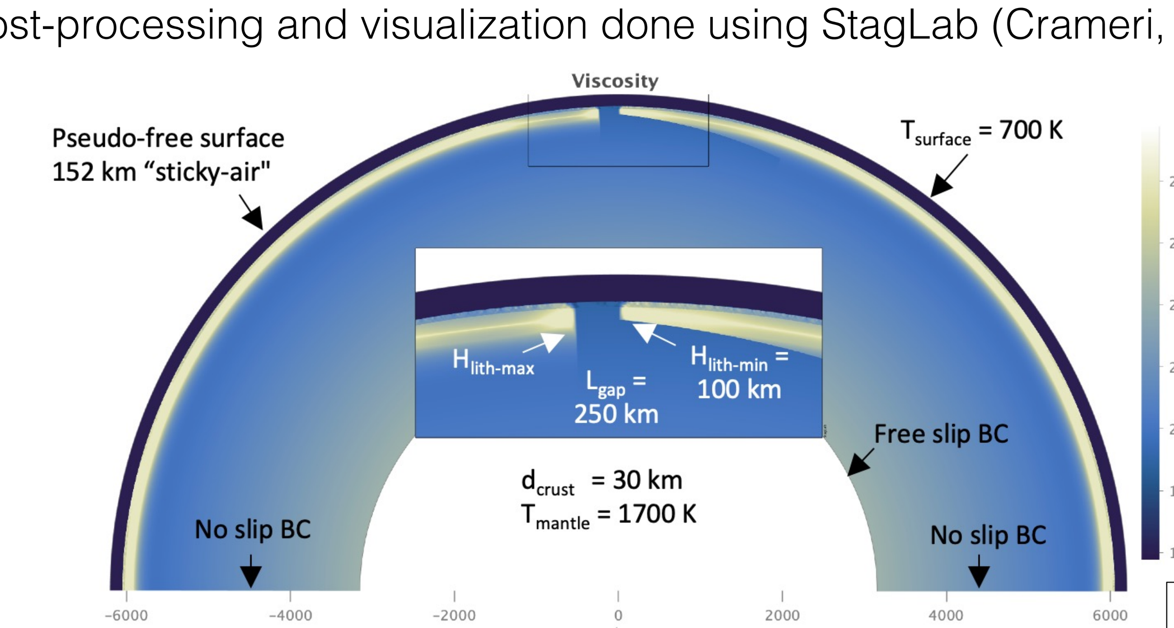

Fig. 2

Phase Transitions and Subduction Evolution

- Earth-like phase transitions were adjusted to shallower depths due to Venus's lower gravity (adapted from *Ogawa and Yanagisawa* [2014]) (Fig. 3)
- The postspinel phase boundary deflection (710 km) is juxtaposed with the "basalt barrier" (710-770 km) (Fig. 4)
- Positive plate buoyancy near 710-770 km depth causes slab tip deflection prior to slab breakoff at the surface

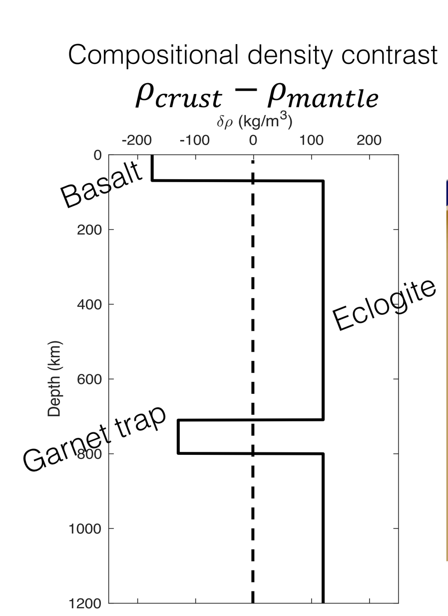

Fig. 3

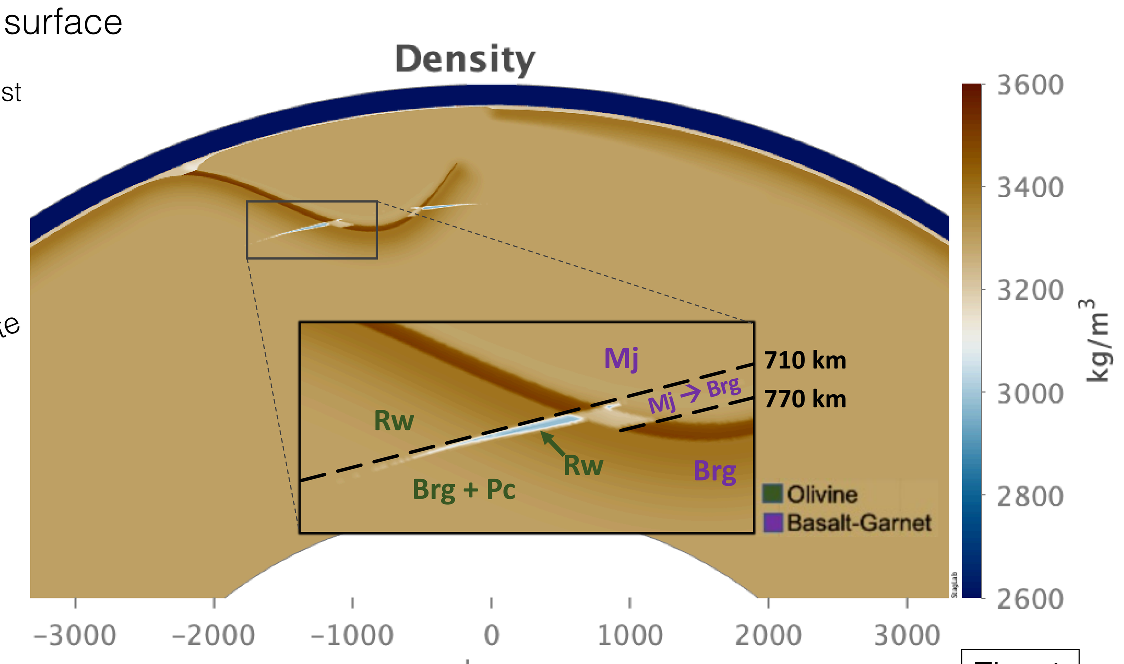

Fig. 4

Plate Buoyancy and Subduction

The total density of the plate (compositional and thermal) was integrated over depth to determine if the plate was positively or negatively buoyant with respect to the ambient mantle. We observed subduction when the net density contrast, $\delta\rho_{plate}$, was positive (i.e. the plate was negatively buoyant). We predicted subduction would not occur when $\delta\rho_{plate}$ was negative (i.e. the plate was positively buoyant). However, several cases of subduction were observed for plates with net-positive buoyancy in the "mixed" zone of the regime diagram (Fig. 5). **We hypothesized that a secondary mechanism can initiate subduction in models where the plate is positively buoyant.**

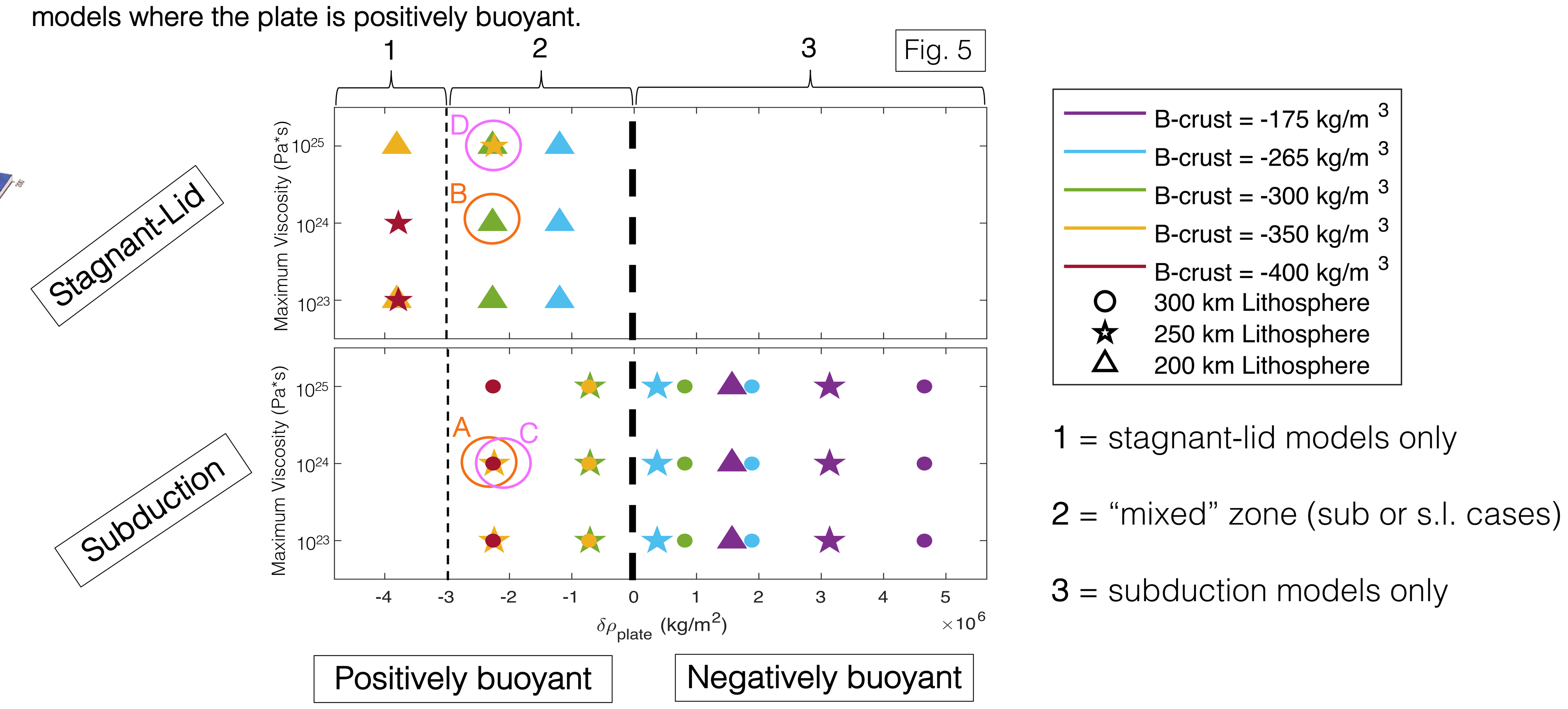

Fig. 5

Initiating Subduction in (+) Buoyant Plates

Condition #1: Horizontal crustal spreading

- Crust covering gap is hotter and less dense than surrounding plate-crust → exerts lateral spreading force on denser plate-crust
- Crust spreading pushes slab tip downward
- Eclogite formation (~70 km depth) shifts plate buoyancy from positive to negative → sustained subduction

*Models A and B have same net plate buoyancy and η_{max}

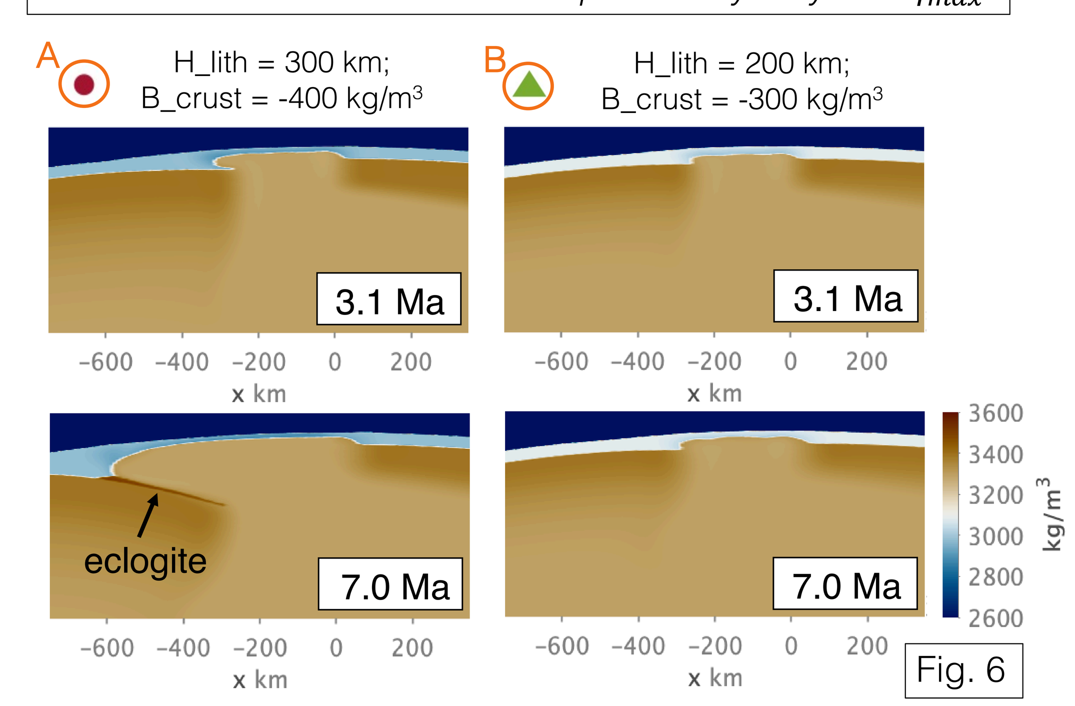

Fig. 6

Condition #2: Weak plates facilitate plate bending

- Strong plate (η_{max} = 10^{25} Pa*s) resists down-turning despite crust spreading over slab tip
- Weaker plate (η_{max} = 10^{24} Pa*s) can bend → subduction

*Models C and D are identical except for η_{max}

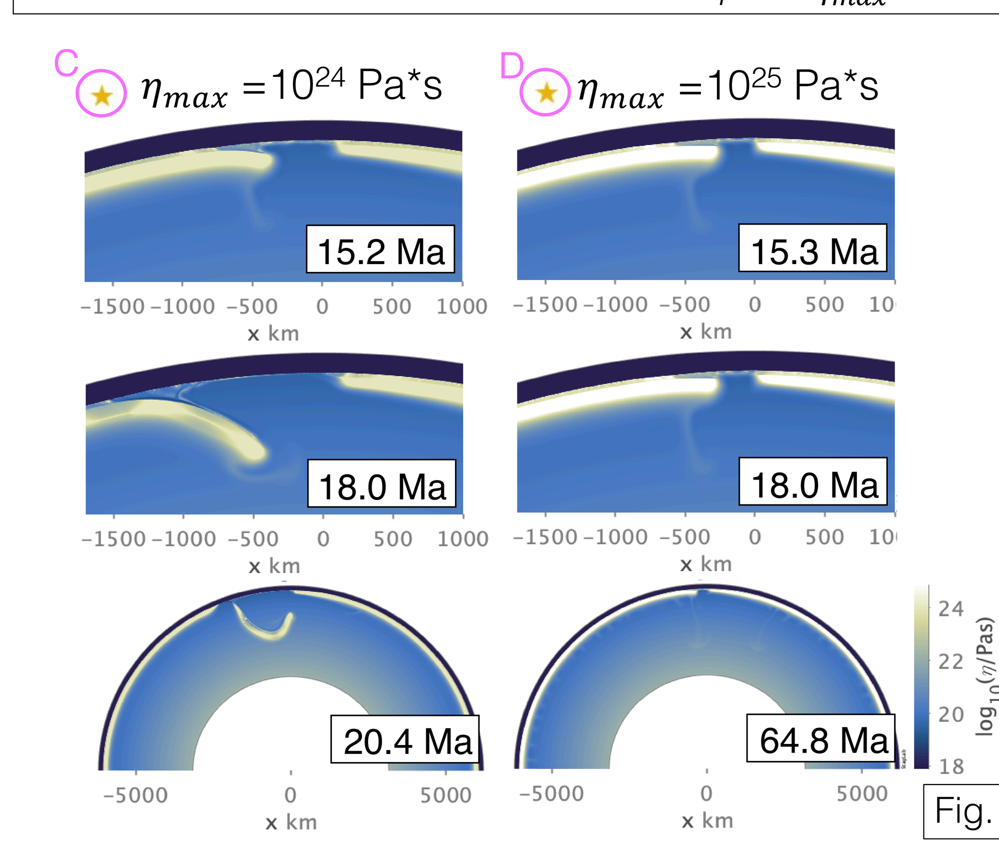

Fig. 7

Conclusions

- Rollback subduction can occur on Venus for either positively (+) or negatively (-) buoyant plates
- Transient horizontal force from crust spreading can initiate plate bending in plates with net (+) buoyancy
- Eclogite formation may change net plate buoyancy from (+) to (-)
  - drives subduction of originally (+) buoyant plates after transient crust spreading force is exhausted

References

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