VENUSIAN IMPACT: STARTING A MOBILE LID. G. T. Euen[1] and S. D. King[1], [1]Virginia Tech 926 W Campus Dr, Blacksburg, VA 24061 (egrant93@vt.edu) (sdk@vt.edu)

Introduction: Earth and Venus are often called sister planets due to their similarities in average radii, densities, bulk composition and location within the solar system. However, their surfaces bare almost no resemblance to each other. Despite the heat within Venus, which we postulate would be similar to Earth, we do not see plate tectonics, nor do we see any form of a dynamic, mobile lid as we do on Earth. The surface of Venus is hypothesized to be in a stagnant lid regime. Based on crater distribution, the surface age could be uniform or variable with an average age of approximately 500 million years [1]. The implication is that the entire crust may have melted and re-solidified roughly 500 million years ago.

There are two prevailing hypotheses for this resurfacing: a progressive process similar to hotspot volcanism on Earth and a cataclysmic event which triggers melting and resurfacing. Recent work has shown that the mobile lid regime requires a component of degree-1 density structure [2]. Without this degree-1 structure, Venus models remain in a plume-dominated, stagnant lid regime. This suggests the need for a mechanism to introduce the degree-1 structure in order to trigger mobile lid behavior. It has also been proposed that large planetary impact was the trigger that initiated plate tectonics on the early Earth [3]. Conditions on early Earth are hypothesized to be similar to modern-day Venus. Here we investigate the role of impacts on the development of mobile lid convection on Venus and whether an impact that initiates mobile lid convection would produce a degree-1 center of mass, center of figure offset.

Methods: Models were run using the geodynamics code ASPECT, Advanced Solver for Problems in Earth's ConvecTion, on the NewRiver cluster at ARC at Virginia Tech. These models are based on previous work done by [3]. Compressible thermal convection is modeled in a 2D slice of a sphere. ASPECT solves equations for conservation of mass, momentum, and energy. The rheology of these tests is given by a composite viscosity law made up of four properties: viscosity due to diffusion creep, viscosity due to dislocation creep, viscosity due to Peierls creep, and effective viscosity due to yielding. The composite viscosity is calculated by taking the reciprocals of these properties, summing them, and taking the reciprocal of that summation.

All impact models were run from the same initial state. Impacts are modeled based on the methods outlined in [4]. Heating of the mantle caused by the impacting body is calculated as a function of pressure due to the shock waves caused by the impact. The pressure of the impact is parameterized as a function of radius from the impact site. The interior of the impact crater, the isobaric core, is set to at a constant peak pressure. Outside this radius the pressure decays exponentially according to $P_s(r) = P_s(r_c)*(r_c/r)^{[-a + b*log(v_i)]}$, where $P_s(r)$ is the pressure due to impact, $P_s(r_c)$ is the peak pressure within the isobaric core, r_c is the radius of the isobaric core, r is distance from the impact, a and b are decay law exponents, and v_i is velocity of the impacting body. In these models, the target and impacting body are assumed to have the same density.

The decay law for calculating the pressure outside of the isobaric core relies on the two exponent values a and b shown above. Numerical experiments done by [5] found values of 1.84 +/- 0.17 and 2.61 +/- 0.14 for these values respectively. Using the hydrocode iSALE, [3] refined these values to 1.68 and 2.74 respectively. Results of these simulations can be found in the supplemental material of [3].

Results: Impacting bodies of radius 50 km, 200 km, and 500 km are shown in Figures 1, 2, and 3 respectively. The larger the impacting body, the deeper into the mantle the shock waves penetrate. Maximum velocity is used to track whether models are in stagnant lid or mobile lid regime. Models stay below 1 cm/yr before the impact. Small impacts cause a spike in maximum velocity which then diminishes close to the original value. Larger impacts cause massive spikes in maximum velocity on the order of m/yr. These also diminish, but they then plateau at higher values showing the surface is now mobile. Figure 4 shows an example plot of maximum velocity based on an impacting body of 200 km radius.

Conclusion: Based on these models, a planet in stagnant lid conditions, such as Venus, can evolve into one of three states after an impact. These states are determined by the size of impacting body. If the impacting body is less than 75 km in radius, the stagnant lid is unbroken and continues to be the dominant regime across the planet. If the impacting body is greater than 75 km in radius, the stagnant lid is broken in the area near the impact, triggering transient localized melting and subduction. Over geologic time lithospheric overturn occurs as viscosity becomes dominated by yielding. If the impacting body is very large, greater than 500 km in radius, the stagnant lid is broken with large-scale heating of the mantle causing buoyant uplift that drives melting, subduction, and lithospheric overturn soon after impact. It should be noted that here the categories of impact evolutions imply a sizing of small, medium, and large impacting bodies. Even the "small" category of less than 75 km radius are very large impacting bodies, especially by present standards. This agrees with the findings of [3] who showed that Hadean Earth requires a large impact to initiate plate tectonics.

References: [1] Simons M. et al. (1994) *Science, 264(5160)*, 798-803. [2] King S. D. (2018) *JGR, 123*, 10.1002/2017JE005475. [3] O'Neill C. et al. (2017) *Nature Geoscience, 10*, 10.1038/NGEO3029. [4] Watters W. A. et al. (2009) *JGR, 114*, E02001. [5] Pierazzo E. et al. (1997) *Icarus, 127*, 408-423.

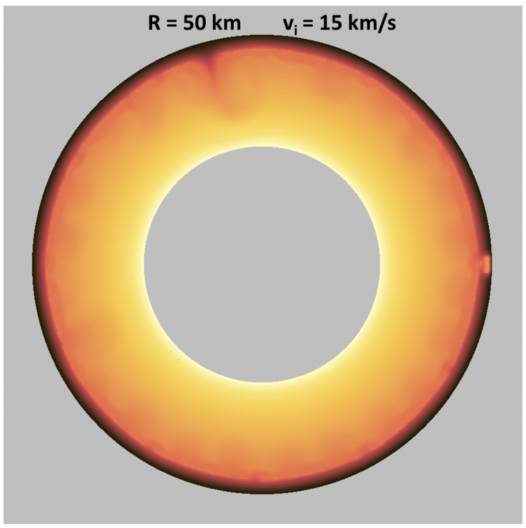

Figure 1: Stagnant lid case impacted by body of radius 50 km. Effects of the impact are contained locally. No major change in planetary conditions develop over geologic time.

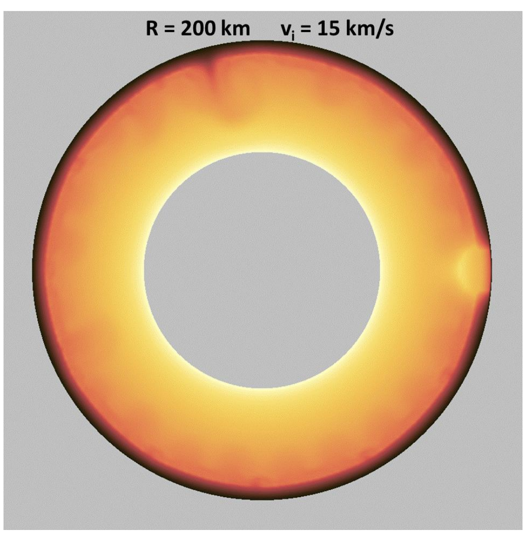

Figure 2: Stagnant lid case impacted by body of radius 200 km. Effects are localized around the impact site. Downwelling, melting, and subduction begin around the impact location. Through geologic time, these effects spread to initiate lithospheric overturn.

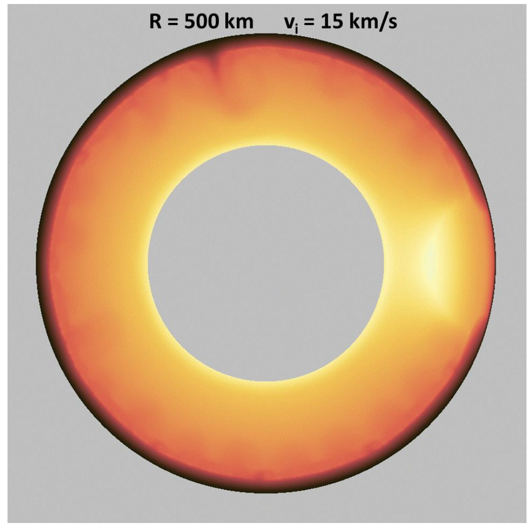

Figure 3: Stagnant lid case impacted by body of radius 500 km. Effects of the impact are immediate and severe. The shock waves penetrate far into the mantle causing large-scale heating. Melting and subduction begin shortly after impact, initiating lithospheric overturn.

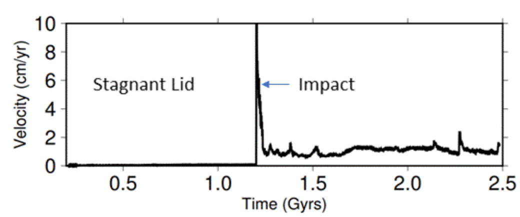

Figure 4: Plot of maximum velocity at the surface of the model shown in Figure 2. The velocity is below 1 cm/yr until impact. The spike diminishes, but plateaus at a new value showing the transition to mobile lid regime.