STATIONARY PLUMES IN STAGNANT LID CONVECTION: APPLICATION TO VENUS S. D. King Department of Geoscience, 4044 Derring Hall, Virginia Tech, Blacksburg, VA (sdk@vt.edu)

Introduction: In high-Rayleigh-number, spherical-shell convection, such as one expects to find in the interiors of large silicate planetary bodies, plumes are expected to migrate, unless they are anchored to fixed structures. Within the Earth both LLSVPs (Large Low Shear Velocity Provinces) and core-mantle boundary topography have been proposed as the mechanism that anchors deep mantle plumes, fixing the location of hotspots [1-2]. It is unclear whether LLSVPs or core-mantle boundary topography might be present on Venus or Mars. The relative stability of volcanic features on Mars and Venus, which are thought to be related to mantle plumes, has not be satisfactorily explained.

Here I present high-Rayleigh-number, stagnant-lid, spherical-shell convection calculations where plumes seeded by the structure of the initial condition persist in a stable configuration for more than 1.5 Gyr (Fig. 1).

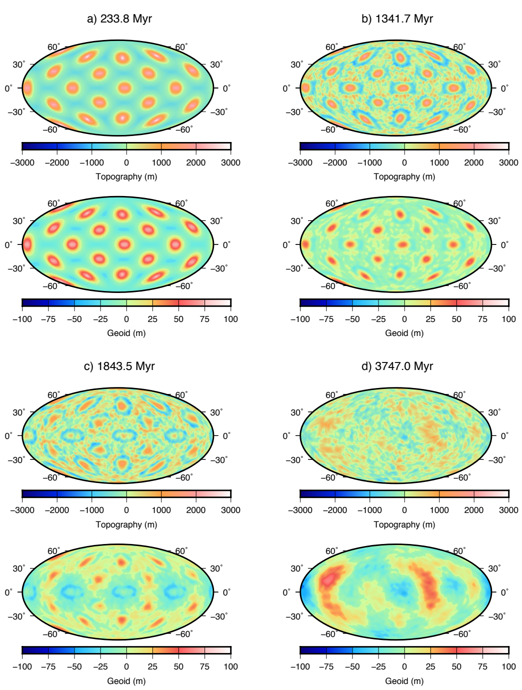

Fig. 1: Calculation with *symmetric* initial condition (*l*=8,*m=4)*.

I show that in these calculations, topography on the base of the stagnant lid (i.e., the lithosphere-asthenosphere boundary) is responsible for the spatial stability of the plumes. If there is long-wavelength symmetry in the initial plume distribution, this long-wavelength symmetry can prevent the lithosphere from becoming unstable and overturning, leading to a significantly over-thickened lithosphere relative to predictions based on scaling laws. This is confirmed by considering an identical calculation where the long-wavelength symmetry in the plume distribution is broken (Fig. 2). In the calculations considered, long-wavelength means a significant component of degree-1 or degree-3 spherical harmonic perturbation to the initial condition. Odd spherical harmonic initial conditions higher than degree 8 do not lead to models with lithospheric overturns and these short-wavelength initial condition models revert to a stable pattern similar to Fig. 1.

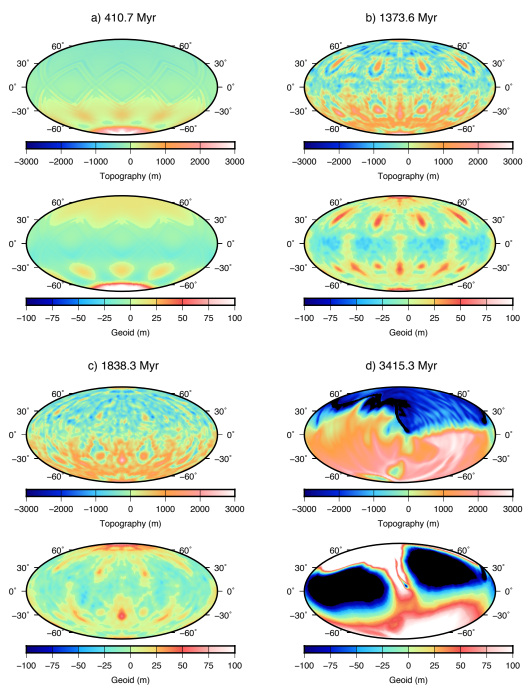

Fig. 2: Calculation with a long-wavelength *anti-symmetric* initial condition (*l*=1,*m*=0).

Application to Venus: The geoid of Venus differs significantly from Earth and Mars in that the spectral power is not dominated by the longest wavelengths [c.f., 3]. Unlike Earth there is a strong correlation between geoid and topography on Venus up to degrees 40 with a notably weaker correlation for degree 2 [e.g., 4]. The small offset between the center of mass and center of figure of Venus cannot be reconciled with the significant dense 'pile' of cold material deep in the Venusian mantle that is expected from a 'catastrophic' resurfacing event [5].

A giant impact has been proposed to explain the retrograde motion of Venus [6] and, a giant impact has the potential to generate an anomalous, anti-symmetric (initial or early in solar system history) thermal condition near the surface of the planet. In this work I consider the effect of a giant impact on the stability of the Venusian lithosphere by systematically varying the near-surface, spherical harmonic initial condition in calculations otherwise identical to Fig. 1 while holding all other parameters fixed. As has been previously shown [6] impactors with a radius greater than 300 km have a global effect on a coupled atmospheric/mantle model; however I will show that an even larger impactor is required to initiate a lithospheric instability in an otherwise stable mantle configuration.

Method. The equations for the conservation of mass, momentum, and energy in a spherical shell geometry assuming an incompressible fluid are solved using CitcomS (version 3.3.2) with a 64 x 64 x 64 element mesh for each of the 12-cubes within the spherical shell [7]. The Rayleigh number is fixed at 3.18×10^{8}. Free-slip boundary conditions are applied to both the surface and the core-mantle boundary. The surface temperature is held constant at 460 ^{o}C, and the initial core-mantle boundary temperature is 3980 ^{o}C (the core-mantle boundary temperature includes a 0.3 ^{o}C/km adiabatic gradient added to the temperature in the calculation of core thermodynamics). The calculations use an initial mantle potential temperature of 2282 ^{o}C (potential temperature is the temperature at zero pressure, i.e., without the adiabatic gradient. A single temperature perturbation of 20 ^{o}C is added at the middle depth of the spherical shell. The calculations use a temperature-dependent, yield stress rheology [8] with core boundary condition based on analytical models of core cooling [9]. The formulation is similar to the formulation described in Nakagawa and Tackley [9] and Zhang and O'Neill [10].

References: [1] Burke, K. (2011) *Annu. Rev. Earth Planet. Sci. 39,* 1-29. [2] Jellinek, A. M. and Manga, M. (2004) *Rev. Geophys.*, *42,* 10.1029/2003RG000144 [3] Wieczorek, M. A. (2007) In: Treatise on Geophysics, v, 10, pp. 165–206, Elsevier. [4] Pauer, M. et al. (2006) *JGR, 111*, E11012. [5] King, S. D. (in revision), *JGR.* [6] Gillmann, C., Golbeck, G. J., and Tackley, P. J. (2016) *Icarus, 268,* 295—312. [7] Zhong, S., et al. (2000) *JGR, 105***,** 11,063-11,082. [8] H. J. van Heck and Tackley, P. J., (2008) *GRL, 35,* L19312. [9] Nakagawa, T., and Tackley, P. J. (2004), *Earth Planet. Sci. Lett.*, *220,* 107—119. [10] Zhang, S. and O'Neill, C. (2016) *Icarus, 265,* 187—208.