Modeling Venusian resurfacing mechanisms: Progressive surface volcanism versus catastrophic mantle overturn, and a comparison to observed Venus topography, geoid, and thermal emissivity anomalies

Aaron C. Prunty¹ (pruntya@vt.edu), Scott D. King² (sdk@vt.edu)
¹Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061

INTRODUCTION

Surface observations of Venus, in particular topography, crater population distributions, and volcanic features, suggest a relatively recent global resurfacing event approximately 750 Ma [1-4].

Progressive surface volcanism, assumed to originate from deep mantle upwellings [13], implies an instability at the core-mantle boundary. Convective mantle overturn, on the other hand, implies a lithospheric instability. The two end-member mechanisms therefore yield starkly different thermal evolutions of the planet [10, 14].

Utilization of observed long-wavelength topography, global geoid, and thermal emissivity anomalies coupled with insight from numerical modeling provides a means to compare predictions from modeling the two end-member mechanisms.

MODELING

We perform high-resolution 3D spherical convection calculations using CitcomS, a finite element code that solves the principle governing equations of conservation of mass, momentum, and energy for the anelastic, incompressible, viscous, thermo-chemical convection problem:

\[ \nabla \cdot \mathbf{v} = 0 \]
\[ -\nabla P + \nabla \left( \eta \left( \nabla \mathbf{u} + \nabla \mathbf{u}^T \right) \right) + RaT \mathbf{u} \cdot \mathbf{n} = 0 \]
\[ \frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = \nabla \cdot \left( \eta \left( \nabla \mathbf{u} + \nabla \mathbf{u}^T \right) \right) + RaT \mathbf{u} \cdot \mathbf{n} + \mathbf{F} \]

where \( P \) is pressure, \( \mathbf{u} \) is velocity, \( \eta \) is viscosity, \( Ra \) is Rayleigh number, \( T \) is temperature, \( \mathbf{n} \) is normal to the domain boundary, and \( \mathbf{F} \) is a body force.

We modeled the catastrophic resurfacing mechanism to infer the thermal evolution of Venus. Degree-1 and multiple, shorter-wavelength perturbations were chosen as two distinct initial conditions to test the affects of the mode of mantle overturn on the observed geoid and topography (Figure 3).

RESULTS

We modeled the catastrophic resurfacing mechanism to infer the thermal evolution of Venus. Degree-1 and multiple, shorter-wavelength perturbations were chosen as two distinct initial conditions to test the affects of the mode of mantle overturn on the observed geoid and topography (Figure 3).

DISCUSSION & CONCLUSIONS

Our initial results show that catastrophic resurfacing can occur at Rayleigh numbers of the order of 10^6 with a yield stress of the order of 20-400 MPa, consistent with the results of van Heek and Tackley [15]. We see that the degree-1 mode of mantle overturn yields a smoother geoid with a larger range of variation than does the multiple, shorter-wavelength mode of mantle overturn. Also, the degree-1 mode of mantle overturn yields a smoother topography with a smaller range of variation than does the multiple, shorter-wavelength mode of mantle overturn. Because the modeled Venus data (Figure 1) manifests a shorter-wavelength, higher degree geoid and topography, we conclude that the shorter-wavelength, multiple instability mode of mantle overturn appears to be more relevant than does the degree-1 mode of mantle overturn.

We aim to compare the two modes of mantle overturn with the same mantle parameters in future calculations. Additionally, future work will include:

- systematically increasing the Rayleigh number in order to map out the behavior of mantle overturn as a function of Rayleigh number and yield stress
- assess the role of phase transformations and depth-increasing viscosity
- determine under what conditions resurfacing occurs as a single, global event and as several smaller-scale regional events closely spaced in time
- analyze whether these two cases can be distinguished using the model geoid, topography, and heat flow after the overturn events by examining if, and how long, the signature of cold ‘subducted’ material in the deep mantle remains observable in the geoid, topography and heat flow
- determine whether we can generate stable plume structures consistent with known surface topography, geoid, and thermal emissivity data, as well as estimate the amount of melt produced by global resurfacing events
- determine whether volcanic resurfacing and lithospheric overturn can coexist in tandem or are in fact mutually exclusive mechanisms.

REFERENCES


ACKNOWLEDGEMENTS

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TABLE 1. Parameters for temperature-dependent rheology and lithospheric yielding

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<tr>
<th>Quantity</th>
<th>Non-D Value</th>
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<td>Activation Energy</td>
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<td>Yield Stress</td>
<td>Reference Viscosity</td>
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TABLE 2. Summary of model parameters distinguishing the degree-1 mode of mantle overturn and the multiple shorter-wavelength instability mode.

<table>
<thead>
<tr>
<th>Mode of Mantle Overturf</th>
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<th>Multiple, short-wavelength instabilities</th>
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FIGURE 1. Venus spherical harmonic models of global topography and geoid [16].

FIGURE 2. Spectral plot of Venus spherical harmonic gravity (SHG210PA01 and SHG210UA01) and topography (VenusTopo719) models.

FIGURE 3. Comparison of geoid and topography for degree-1 mantle overturn (left) and shorter-wavelength, multiple instability subduction (right).

FIGURE 4. Comparison of rms velocity and temperature for degree-1 mantle overturn (left) and shorter-wavelength multiple instability subduction (right).

FIGURE 5. 3D sections of models with iso-surface showing cold, downwelling material for degree-1 mantle overturn (left) and shorter-wavelength, multiple instability overturn (right).