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3-D Spherical modelling of the thermo-chemical evolution of Venus' mantle and crust

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Background

Several first-order aspects of the dynamics of Venus' mantle remain poorly understood. These include (i) how Venus' mantle loses its radiogenic heat, which is expected to be about the same as Earth's, despite the presence of stagnant lid convection. Hypotheses that have been advanced (summarised in [1]) are conduction through a thin lithosphere, episodic overturn of the lithosphere, magmatic heat transport, and concentration of almost all heat-producing elements into the crust, but there are problems with all of these taken individually. A thick lithosphere may not be consistent with admittance ratios, magmatic heat transport would require a too-large resurfacing rate, and a large concentration of heat-producing elements in the crust would cause weakness and possibly melting in the deep crust. (ii) The relatively long-wavelength distribution of surface features, which is surprising because numerical models and analogue laboratory experiments of stagnant-lid convection produce relatively short-wavelength convective cells. (iii) The inferred (from crater distributions [2]) relatively uniform surface age of 500-700 Ma. (iv) Whether the highlands are above mantle downwellings as on Earth or above mantle upwellings [3]. (v) How the mantle can have outgassing only 25% of ^{40}Ar [4] but supposedly most of its water [5]. (vi) The cause of coronae and relationship to mantle processes [6].

Model

To study some of these questions, we are performing integrated thermo-chemical convection modelling of Venus' evolution over 4.5 billion years, in 3-D spherical geometry as well as 2-D spherical annulus geometry [7]. These models include realistic ("laboratory") rheological parameters for diffusion creep and dislocation creep based on [8][9], which are also composition-dependent, and plastic yielding based on Byerlee's law, which might cause changes in tectonic regime (e.g., episodic plate tectonics). Crustal formation and the resulting differentiation of the crust and mantle are modelled using a self-consistent melting criterion, which also allows outgassing and trace element partitioning to be tracked [10][11], as well as the mean age of the crust. Phase transitions in both the olivine system and pyroxene-garnet system are included. The concentration of heat-producing elements is assumed to be the same as in bulk silicate Earth and decreases with time, and cooling of the core is tracked using a parameterised core heat balance. Geoid and surface topography are calculated using a self-gravitating formulation. Thus, the model constitutes an attempt to incorporate as much realism as is presently feasible in global-scale 3-D spherical simulations. Simulations are performed using StagYY, which uses a finite volume multigrid solver on the Yin-Yang spherical grid [12], and is developed from the earlier cartesian Stag3D [13].

Results

We are running a systematic suite of simulations varying uncertain properties and parameters related to rheology, melting&eruption, and initial condition, and compare model results to observations of surface topography (general & hypsometric distribution, spectrum), geoid (amplitude, spectrum, admittance ratios, correlated with topography), mean surface age and distribution of surface ages, crustal deformation rates in the last part of the evolution (e.g., [14]), crustal thickness, outgassing of radiogenic argon (^{40}Ar) and of nonradiogenic volatiles (e.g., water), and the time evolution of heat flux through the CMB. Of particular interest is whether a smooth

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evolution can satisfy the various observational constraints, or whether episodic or catastrophic behaviour is needed, as has been hypothesised by some authors.

Simulations in which the lithosphere remains stagnant over the entire history indicate that over time, the crust becomes as thick as the mechanical lithosphere, with delamination occuring from its base, and magmatism being the dominant heat transport mechanism. A thick crust is a robust feature of these calculations. Higher mantle viscosity results in larger topographic variations, thicker crust and lithosphere and higher admittance ratios; to match those of Venus, the upper mantle reference viscosity is about 10^{20} Pa s and internal convection is quite vigorous. Several large plumes persist throughout the model history, as the core does not cool as much as in Earth due to the lack of slabs arriving at the CMB.

The most successful results in matching observations are those in which the evolution is episodic, being in stagnant lid mode for most of the evolution but with 2-3 bursts of activity caused by lithospheric overturn. If the last burst of activity occurs ~1 Ga before present, then the present day displays low magmatic rates and mostly conductive heat transport, consistent with observations. Geoid spectra and admittance ratios are also compatible with observations in some cases. In ongoing work we are examining the effect of crustal rheology and a more accurate melting treatment.

Bibliography

[1] Turcotte, D. L. (1995) *JGR, 100*, 16931-16940.

[2] Hauck, S. A. et al. (1998) *JGR, 103*, 13635-13642.

[3] Bindschadler, D. L. et al. (1992) *JGR, 97*, 13495-13532.

[4] Kaula, W. M. (1999) *Icarus, 139*, 32-39.

[5] Kaula, W. M. (1994) *Phil. Trans. R. Soc. Lond. A, 349*, 345-355.

[6] Johnson, C. L. and Richards, M. A. (2003) *JGR 108*, doi:10.1029/2002JE001962.

[7] Hernlund, J. W. and P. J. Tackley (2008) *PEPI*, 171 (1-4), 48-54.

[8] Karato, S. and P. Wu (1993) *Science, 260*, 771-778.

[9] Yamazaki, D. and S. Karato (2001) *Amer. Mineral*., 86, 385-391.

[10] Nakagawa, T. and P. J. Tackley (2005) *Gcubed, 6*, doi:10.1029/2005JB003751.

[11] Xie, S. and P. J. Tackley (2004) *PEPI, 146*, 417-439.

[12] Tackley, P. J. (2008) *PEPI*, 171 (1-4), 7-18.

[13] Tackley, P. J. (1993) *GRL, 20*, 2187-2190.

[14] Grimm, R. E. (1994) *JGR, 99*, 23163-23171.

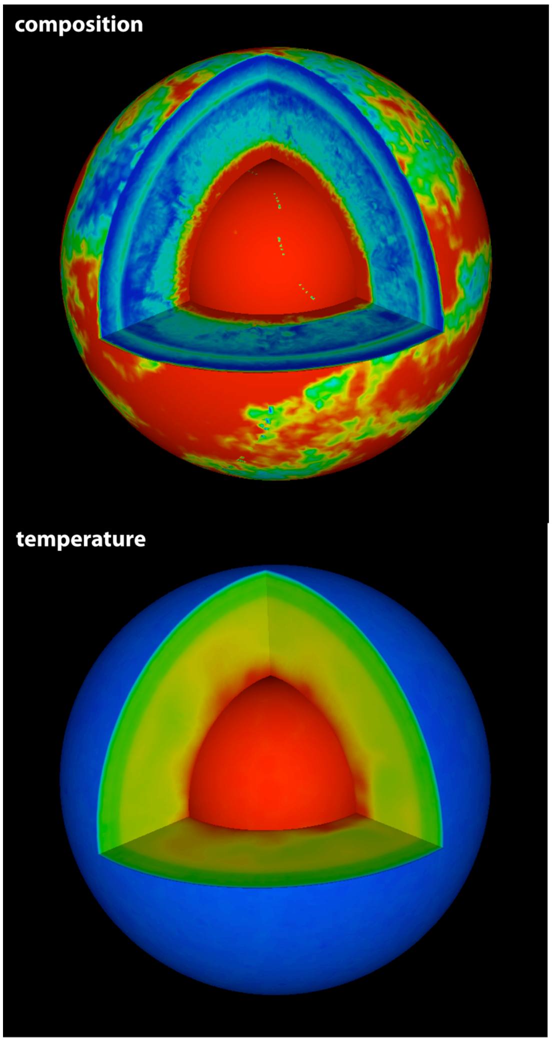

Figure 1. A 3-D spherical case with episodic lithospheric overturn, after 4.5 billion years. The last overturn event was >1 Ga before present. A somewhat stratified compositional structure (top, red=crust and blue=harzburgite) is facilitated by episodic crustal subduction. Surface heat flow is mostly conductive at the end.