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Influence of intrusive magmatism on Venus' tectonics and long-term thermo-chemical mantle evolution

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Abstract

Here the models of [1] are extended. Numerical convection models of the thermochemical evolution of Venus are compared to present-day topography and geoid, recent resurfacing history and surface deformation. The models include melting, magmatism, decaying heat-producing elements, core cooling, realistic temperature-dependent viscosity and either stagnant lid or episodic lithospheric overturn.

In [1] it was assumed that all magmatism is extrusive, i.e. melt generated in the lithosphere is immediately placed at the surface at the surface temperature, which constitutes the well-known "heat-pipe" mode. This leads to a cold, strong crust/lithosphere. It was found that in stagnant lid convection the dominant mode of heat loss is this magmatic heat pipe, which requires massive magmatism and produces very thick, cold crust, inconsistent with observations. Partitioning of heat-producing elements into the crust helps but does not help enough. Episodic lid overturn interspersed by periods of quiescence effectively loses Venus's heat while giving lower rates of volcanism and a thinner crust. Calculations predict 5–8 overturn events over Venus's history, each lasting ~150 Myr, initiating in one place and then spreading globally. During quiescent periods convection keeps the lithosphere thin. Magmatism keeps the mantle temperature constant over Venus's history. Crustal recycling occurs by entrainment in stagnant lid convection, and by lid overturn in episodic mode. Venus-like amplitudes of topography and geoid can be produced in either stagnant or episodic modes, with a viscosity profile that is Earth-like but shifted to higher values. The basalt density inversion below the olivine-perovskite transition causes compositional stratification around 730 km; breakdown of this layering increases episodicity but far less than episodic lid overturn. The classical stagnant lid mode with interior temperature approximately a rheological temperature scale lower than T_CMB is not reached because mantle temperature is controlled by magmatism while the core cools slowly from a superheated start. Core heat flow decreases with time, possibly shutting off the dynamo, particularly in episodic cases.

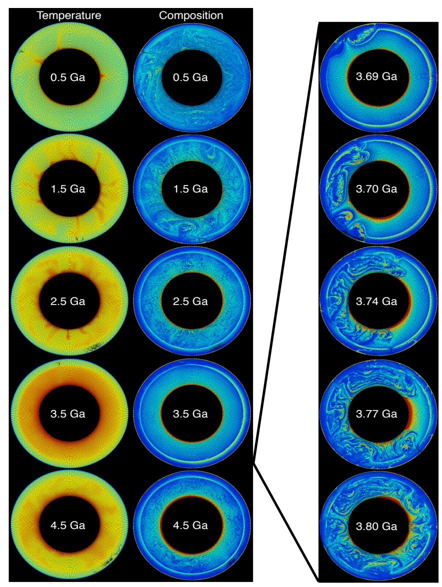

Figure 1: Venus' evolution with intrusive magmatism, showing detail of a global lithospheric overturn event.

However, on Earth and probably on other planets most magmatism is intrusive rather than extrusive. Intrusive magmatism warms and weakens the crust, resulting in substantial surface deformation and a thinner crust. Here we find that global lithospheric

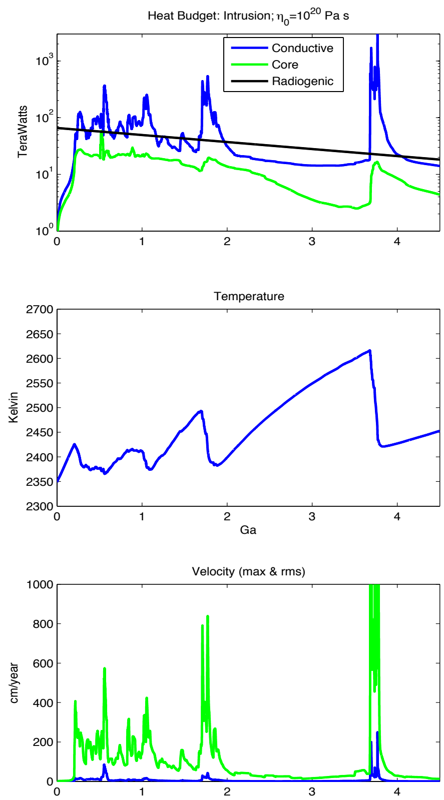

Figure 2: Time-evolution of heat budget, temperature and velocity, showing episodicity induced by magmatic intrusion.

overturn events can occur without the need for plastic yielding, due to massive magma intrusion into the crust/lithosphere. This is further enhanced by using a basaltic rheology for the crust instead of assuming the same rheological properties as for the mantle. Here we quantitatively analyse the resulting surface deformation and other signatures, and compare to observations in order to constrain the likely ratio of intrusive to extrusive magmatism.

In summary, the magmatic mode makes a first-order difference to the large-scale tectonic evolution of Venus, and most likely other terrestrial planets.

Reference

[1] Armann, M., and Tackley, P. J., Simulating the thermochemical magmatic and tectonic evolution of Venus's mantle and lithosphere: Two-dimensional models, J. Geophys. Res., 117, E12003, doi:10.1029/2012JE004231, 2012.