Geophysical Research Abstracts
Vol. 14, EGU2012-6833-1, 2012
EGU General Assembly 2012

Venus thermal evolution and outgassing history: constraints from numerical simulations and Venus Express observations

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The Venus Express mission has revealed areas of high emissivity that are indicative of recent volcanism [1]. These areas are also characterized by gravity and topography signatures typical of the presence of active plumes. In an effort to understand the characteristics of these plumes, numerical simulations of heat transfer in a 3D spherical shell have been carried out [2]. These numerical simulations can handle large viscosity variations [3]. We have examined 16 cases with Temperature differences from 1140 to 2280°K, non dimensional internal heating of 0 to 10, and mantle viscosities of 10**20 and 10**21 Pa.s. The equivalent activation energy is ∼485 kJ/mole. Convective Rayleigh numbers range from 10**5 to 3x10**7. Increasing internal heating increases the number of hot plumes. The limit occurs when the mantle temperature becomes so large that the temperature difference across the hot thermal boundary layer drops below the viscous temperature scale [4], at which point there is insufficient buoyancy to give rise to plumes. Such a case contradicts the observations. Including a lower mantle viscosity value of 10**20 Pa.s allows for larger values of internal heating that permit hot plumes. However, the highest non-dimensional heating rate in cases with mantle plumes achieved to date (HS = 10) is lower than the value of 50 than predicted by scaling internal heating from Earth to Venus. Partitioning of radiogenic elements into the crust would lower the mantle concentration, but is inconsistent with retaining volatiles in the mantle. Thus our simulations suggest that the mantle is heating up at a rate of about 100 K/byr.

In half of the cases, the hot plumes produce pressure release melting over several 100s km beneath the conductive lid, intersecting the wet solidus, but not the dry solidus. Wet melting throughout much of the upper mantle suggests that it may be lacking in light elements and more fully outgassed than the lower mantle. Over time the upper mantle may have lost significant volatiles. Assuming 50 ppm water in the mantle, 10 plumes with a buoyancy flux of 500 kg/s erupting for 4 m.y. will outgas approximately the amount of water in the lower atmosphere [5]. Volcanism may have gone through a transition from more wide-spread, wet melting in the upper mantle to more localized melting in mantle plumes carrying unmelted, volatile rich material from depth.

Part of this work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Government sponsorship acknowledged.

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