A SIMPLE COOLING MODEL FOR THE CESSATION AND DISTRIBUTION OF VOLCANISM ON VENUS. C. P. Orth[1], V. S. Solomatov[1], C. C. Reese[1], and J. W. Head[2], [1]Department of Earth and Planetary Sciences, Washington University in Saint Louis, St. Louis, MO 63130 USA (corth@epsc.wustl.edu), [2]Department of Geological Sciences, Brown University, Providence, RI 02912 USA.

Introduction: Two main groups of models have been proposed to explain the statistical distribution of craters on Venus [1,2]. Schaber et al. [1] proposed that ~ 500 million years ago (the mean surface age of the planet, T) Venus underwent catastrophic resurfacing followed by relatively minor resurfacing rates since then. The stratigraphic analysis by Basilevsky and Head [3] is generally consistent with this model. They argue that the duration of resurfacing was relatively short, $\sim 0.1T$. Phillips et al. [2] presented an alternative model according to which the equilibrium population of craters is a result of small-scale resurfacing that occurred in different places of the planet at different times. According to the statistical analysis of crater distribution by Hauck et al. [4] the duration of resurfacing may be up to $\sim 0.5T$.

Various geodynamical models have been proposed to explain the mechanisms of resurfacing of Venus [5-13] Reese et al. [13] argued that the models of magmatic resurfacing have the strongest observational and theoretical support. They showed that in the absence of plate tectonics, Venus was likely to be substantially melted by radiogenic heating during some of its history and that the resurfacing "event" may simply reflect the waining stages of the cessation of magmatism. To test this hypothesis further we focus on the very last stages of magmatism (the observable history of Venus), that is from the time when "dry" patches began to appear. Here we consider a spherical model of cooling history of Venus starting with the first appearance of dry patches and calculate the evolution of volcanism using different sets of assumptions, regarding the intensity of convection, initial temperature and initial lid thickness. The goal is to determine a the evolution of volcanic activity on Venus and compare the results to geologic observations.

Model: We assume that at some point in Venusian history the planet was substantially molten [13] and large amounts of magmatism were present. We do not consider the initial stage of cooling and resurfacing when the volcanic rates were likely to be large enough to form a global magma ocean. To calculate the evolution and distribution of volcanism, we use a parameterized form of the solidus and liquidus temperature profiles in the crust and upper mantle. The initial temperature within the lid and upper mantle is defined through a simple error function which is modified to follow the wet adiabat in the partially molten regions and the dry adiabat within the subsolidus regions [15]. The decline in volcanism is caused by the growth of a conductively cooling lid with variable initial thickness. The convective heat flux at the base of the lid is assumed to be negligible. At some point the lid grows to a depth where the temperature profile no longer intersects the solidus and melting will cease. Because of the initial lid thickness variations, the timing of the cessation of magmatism varies spatially. The initial variations in the lid thickness are either assumed to be a random combination of spherical harmonics or a combination that correlates with the present-day surface topography. In the latter case, we use the spherical harmonics up to degree and order 20 from [14]. We also consider the effects of the solid/melt density inversion (around 300 km). Only melt generated above the density inversion depth is extracted. After the melt is extracted the residuum is replenished through convective mixing.

Results: The initial lid thickness and initial thickness variation are varied from 30 km to 300 km and from 5% to 75% respectively. For the cases where the solid/melt density inversion was considered it was set to 300 km. For the initial lid thicknesses of 30 and 100 km, the solid/melt density inversion has very little effect. In the cases with initial lid thickness of 300 km and variations in the lid thickness of 5% and 10% no melt escapes. The preliminary results are summarized in Table 1 and in Figure 1.

L_i (km)	ΔL_i (%)	T(K)	t_v (Myr)	SA(%)			
30	5	1472	0.6	79.1	16.9	3.1	0.9
	10		1.2	60.2	34.8	3.9	1.1
	25		3.0	38.0	55.3	5.3	1.4
	50		5.3	20.5	68.8	8.8	1.9
	75		6.6	10.0	70.5	16.2	3.3
100	5	1673	5.6	91.0	6.3	2.1	0.6
	10		13	74.7	21.0	3.3	1.0
	25		33	44.6	49.3	4.9	1.2
	50		57	23.4	66.3	8.4	1.9
	75		72	11.9	69.0	16.1	3.0
300	5	1768	–	–	–	–	–
	10		–	–	–	–	–
	25		0.0	100	0.0	0.0	0.0
	50		210	97.1	1.6	0.9	0.4
	75		340	91.7	4.7	2.5	1.1

Table 1: Summary of preliminary results in terms of initial lid thickness, L_i, and initial lid thickness variations, ΔL_i. The potential temperature, T; duration of cessation of volcanism, t_v; and percentage of surface area covered by each of the four stratigraphic units, SA, are listed from oldest (left) to youngest (right).

Discussion: Comparison of the model results to calculations of the present day lid thickness, potential temperature, and total time for the cessation of volcanism as well as to observations of the topography, geoid, and global distribution of stratigraphic units places constraints on the history of Venus and the initial conditions at the beginning of patchy volcanism. The present day lid thickness obtained in the models is consistent with previous estimates [12,16]. and is largely controlled by the conductive cooling time 0.5-1 billion years.

The initial lid thickness 30 km seems unrealistic. The potential temperature for the models with initial lid thickness of 30 km are too cold compared to Earth as well as the values predicted by parameterized models of thermal evolution of Venus with realistic rheologies [13]. If a magma ocean existed on Venus before the observable geologic history, then it is unlikely that the potential temperature is much lower than

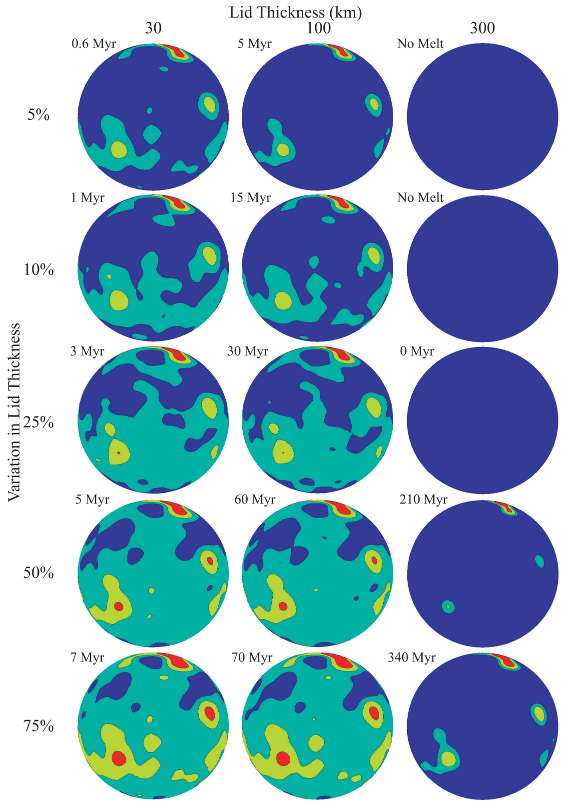

Figure 1: Models of global stratigraphy with the units derived from four equal time intervals during the duration of cessation of volcanism (listed to the upper left of each sphere). From oldest to youngest they are: blue, light blue, yellow, and red.

the temperature for the rheological transition [17], which is ∼1700-1800 K, depending on the composition. Also, the initial lid thickness of 30 km seems to predict too quick a cessation of magmatism (less than 10 Myr).

The models with the initial lid thickness 100 km are generally consistent with the predicted timing for the cessation of volcanism (∼10 - 100 Myr). However, in the models with small relief (5-10%) most of the planet is resurfaced during the first quarter of the total duration of volcanic activity (Table 1) which seems too short compared to geological observations. Models with large initial relief (25-75%) produce an acceptable resurfacing history.

Models with initial lid thickness 300 km and small lid thickness variations produce almost no melt due to solid/melt density inversion (less than our resolution limit). In models with large initial relief the volcanism lasts 200-300 Myr years although most of the planet is resurfaced in less than a quarter of that time.

Although a purely conductive cooling model gives reasonable temperature, lid thickness and the duration of the resurfacing, it needs to include other factors such as plumes and crustal thickness evolution. For example, the oldest to youngest regions in our model would occupy correspondingly from the lowest to highest topography. This could explain at least to first order the topography-age correlations between the volcanic rises and the surrounding lowland plains. However, this model cannot explain the fact that the oldest terrains (tessera and other heavily tectonized terrains), tend to concentrate at higher elevations [18,19]. The high elevation of these terrains (such as Fortuna, Ovda and Thetis) is likely to be due to a thick crust [20,21]. Also, without continuing plume activity, the variations in the lid thickness will become very small and would not be able to generate the observed gravity and topography anomalies beneath the volcanic rises (such as Beta, Atla, Western Eistla and Bell). Besides, without plumes, the volcanic rises tend to subside with time rather than grow as suggested by geological observations and geodynamic models [16,22]. Thus, addition of the initial crustal thickness variations, calculations of crustal growth and plumes are among the factors that need to be considered in the future.

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