VENUS PANCAKE DOME FORMATION: MORPHOLOGIC EFFECTS OF A COOLING-INDUCED VARIABLE VISCOSITY DURING EMPLACEMENT;
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The distinctive steep-sided "pancake" domes discovered in the Magellan images of Venus have morphologies that suggest formation by a single continuous emplacement of a high viscosity magma [1]. A resemblance of the venusian domes to—much smaller—terrestrial rhyolite and dacite volcanic domes has prompted some authors to suggest that the domes on Venus also have high silica compositions [1, 2] and thus high viscosities. However, viscosity is a function of crystallinity as well as silica content in a magma, and thus increases as a result of magmatic cooling. To investigate the effect of a cooling-induced viscosity increase on dome morphology, we are modeling the domes as radial viscous gravity currents that cool during emplacement.

The spreading of radial viscous gravity currents has been previously discussed and solved for constant viscosities using a similarity solution approach [3, 4]. If the dome emplacement is modeled as the release of a fixed fluid volume, the cooling-induced viscosity is primarily a function of time, and may be approximated as

$$\nu = k\, t^{\beta}$$

where ν is kinematic viscosity, k is a constant, t is time, and β is a constant ≥ 0. Figure 1 illustrates viscosity functions for $\beta=0$ (constant viscosity), $0<\beta<1$, $\beta=1$(linear viscosity with time), and $\beta>1$(Magmatic viscosities [5]). For this fixed volume release, time-dependent viscosity case, an approach similar to Huppert's yields a similarity solution valid only for the range $\beta<1$. However, the similarity solution is a good indication of the behavior of the general solution as β increases from the constant velocity case of $\beta=0$ through the $0<\beta<1$ range of the similarity solution and towards the $\beta>1$ range of realistic magmatic viscosity functions. In general, as $\beta \rightarrow 1$for $t\rightarrow\infty$, flow velocity $\rightarrow 0$, and it is reasonable to expect that, in the full solution, the flow would halt in a finite, β-dependent time that is only weakly dependent on composition. If this is the case, the Venus dome morphologies might be the result of the cooling process rather than the initial composition.

A solution of the flow problem for all β is in progress and is obtained by numerically solving the nonlinear partial differential equation

$$\frac{\partial h}{\partial t} - \frac{1}{3}\frac{g}{\nu} r^{-1} \frac{\partial}{\partial r}\left(r h^{3} \frac{\partial h}{\partial r} \right) = 0$$

for flow height as a function of radius and time where h is flow height, t is time, r is radius, g is acceleration of gravity, and ν is viscosity. A full solution to the problem couples the viscosity as an explicit function of temperature predicted by a exterior convection-interior conduction cooling model of the flow during emplacement. An approximate solution may be obtained by using a time-dependent viscosity function determined by a fit to empirical cooling data (e.g.[5]). If the results from the approximate solution follow the general trend illustrated in table one, then the viscosity change resulting from cooling during emplacement will be a significant factor in emplacement and final morphology of volcanic features such as the venusian "pancake" domes, and the composition of the domes will not be uniquely determined by their final morphology

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VENUS PANCAKE DOME FORMATION: Sakimoto, S.E.H. et al

Table 1. viscosity function shapes and flow behaviors for the variable time dependent viscous radial gravity flows described in the text.

Viscosity function shape	β value	Flow behavior as $t \to \infty$
Constant	$\beta = 0$	Flow spreads indefinitely
Concave downward	$0 < \beta < 1$	Flow decelerates
Concave downward	$\beta \to 1$	Flow velocity $\to 0$ as $t \to \infty$
Linear	$\beta \geq 1$	Similarity solution breaks down
Concave upward	$\beta > 1$	Flow will stop (predicted results)

Figure 1. Time dependent kinematic viscosity functions of the form $\nu = k\,t^{\beta}$ where the function shape and flow behavior are related as described in table 1, the units are any compatible set of viscosity and time units, and the magmatic viscosities are in the region where $\beta > 1$ (see text).