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EMPLACEMENT OF VOLCANIC DOMES ON VENUS AND EUROPA. Lynnae C. Quick[1], Lori S. Glaze[1], Steve M. Baloga[2], [1]NASA Goddard Space Flight Center, Code 698, Greenbelt, MD 20771, Lynnae.C.Quick@nasa.gov, Lori.S.Glaze@nasa.gov [2]Proxemy Research, 20528 Farcroft Lane, Laytonsville, MD 20882, steve@proxemy.com.

Introduction: Placing firmer constraints on the emplacement timescales of visible volcanic features is essential to obtaining a better understanding of the resurfacing history of Venus. Fig. 1 shows a Magellan radar image and topography for a putative venusian lava dome. 175 such domes have been identified, having diameters that range from 19 – 94 km, and estimated thicknesses as great as 4 km [1-2]. These domes are thought to be volcanic in origin [3], having formed by the flow of a viscous fluid (i.e., lava) onto the surface.

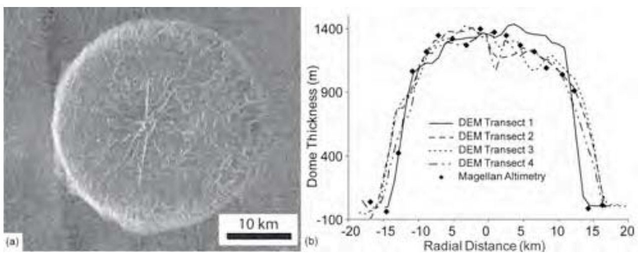

Figure 1. (a) Magellan image of a typical steep-sided dome in the Rusalka Planitia at 3°S, 151°E. (b) Topographic data for the dome shown in (a) with ~20x vertical exaggeration. The four transects depict topography from a digital elevation model generated from stereo Magellan images [4].

Among the unanswered questions surrounding the formation of Venus steep-sided domes are their emplacement duration, composition, and the rheology of the lava. Rheologically speaking, maintenance of extremely thick, 1-4 km flows necessitates higher viscosity lavas, while the domes' smooth upper surfaces imply the presence of lower viscosity lavas [2-3]. Further, numerous quantitative issues, such as the nature and duration of lava supply, how long the conduit remained open and capable of supplying lava, the volumetric flow rate, and the role of rigid crust in influencing flow and final morphology all have implications for subsurface magma ascent and local surface stress conditions.

The surface of Jupiter's icy moon Europa exhibits many putative cryovolcanic constructs [5-7], and previous workers have suggested that domical positive relief features imaged by the Galileo spacecraft may be volcanic in origin [5,7-8] (Fig. 2). Though often smaller than Venus domes, if emplaced as a viscous fluid, formation mechanisms for europan domes may be similar to those of venusian domes [7]. Models for the emplacement of venusian lava domes (e.g. [9-10]) have been previously applied to the formation of putative cryolava domes on Europa [7].

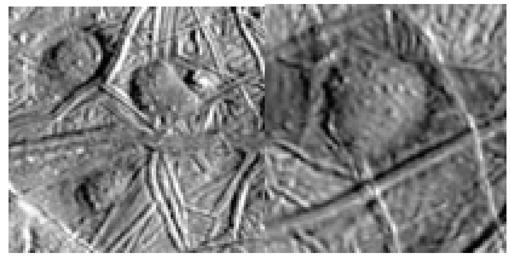

Figure 2. Galileo images of putative cryolava domes on Europa. These domes are approximately 5 km in diameter. Illumination is from the right.

The compositions of europan cryolavas are poorly constrained. Accurate determinations of the viscosities and rheologies of cryolavas on Europa would place constraints on their compositions and could reveal a plethora of information concerning the evolution of the satellite.

Model: Here we investigate the emplacement of volcanic domes, exploring the effect of boundary conditions on the solution of the Boussinesq equation for pressure driven fluid flow in a cylindrical geometry:

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

Akin to previous investigators [9-12], we assume a constant volume of material, and that the dome thickness boundary condition at the source decays over time. An exact analytical solution of (1) for this boundary condition, where the nonphysical singularities present in previous studies of volcanic domes on Earth and Venus [9,11-12] have been removed, was found based on an extended similarity analysis [13].

One approach to modeling the viscous expansion of a dome is to assume that most of the volume is emplaced rapidly, supply terminates, and the dome is formed by subsequent radial relaxation [9-12]. Dome models in [9-12] use a similarity solution with a singularity at the origin. This results in an infinite flow depth at the origin. Because (1) is based on lubrication theory (small Reynolds's number and h/r), it is possible that such a solution may not be valid. In solving (1), we have therefore obtained an alternative approach to that which was used by [10] (upon which [9,11-12] are based). Our approach removes the singularity in the similarity solution by taking advantage of the translational invariance of (1) with respect to time (e.g., [14-15]). We have obtained the following solution for flow thickness:

$$h(r,t) = \frac{h_o}{(1+t/\tau)^{1/4}}\left[1 - \frac{1}{(1+t/\tau)^{1/4}}\frac{r^2}{r_o^2}\right]^{1/3} \quad (2)$$

where the time constant, τ, is given by:

$$\tau = \left(\frac{3}{4}\right)^5 \pi^3 \frac{\nu r_o^8}{gV^3} \quad (3)$$

The dome thickness profile, as described by (2), is finite for all values of r and t. However, finding physically plausible values for r_o and h_o, the radius and thickness, respectively, of the dome at the start of relaxation, is challenging, as this boundary condition assumes that all the material is initially present upon the surface (Fig. 3). Fig. 3 shows that even with an r_o of 7 km, half the final radius, the height at the dome center would have to be 6.4 km, which is unlikely.

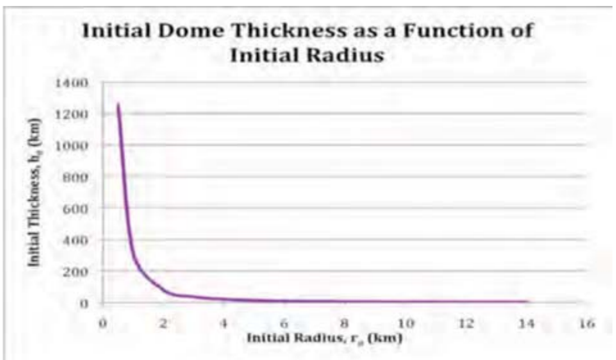

Figure 3. Initial h_o as a function of r_o for a dome that relaxes to a final radius of 14 km and thickness of 1.2 km.

Further, with relaxation commencing when r_o is 2 km, the dome height would be approximately 78 km (Fig. 3), which is no doubt an implausible scenario. This emplacement scenario may therefore only be applicable at the final stage of emplacement. Once this mode is reached, however, the flow front, r_f, advances at a rate that is unexpected for a diffusion-like process, described by (1):

$$r_f(t) = r_o(1+t/\tau)^{1/8} \quad (4)$$

From the definition of τ in (3), dynamic bulk viscosities on the order of 10^{16}-10^{17} Pa-s cannot be precluded, suggesting that this approach may over-predict lava viscosity while under-predicting emplacement time. Further, because the pre-relaxation phase has been ignored in this analysis, the duration of lava supply cannot be estimated. Application of this approach to the dimensions of Venus domes (e.g., Fig. 1) suggests viscosities comparable to rhyolites. However, eliminating the constant volume constraint (e.g., allowing a constant volume flow rate at the vent) may result in lower visocity solutions [13].

The model presented here does not address the issue of time dependent changes in viscosity. Time dependent viscosity was previously examined by [9]. However, the assumed form of the viscosity included the boundary condition of zero viscosity at $t = 0$. Finding a more appropriate form for time-dependent viscosity may result in a viable emplacement scenario for this boundary condition.

Conclusions: Reviewing this model in light of a time dependent viscosity will place constraints on the relaxation of domes over time as well as the role that the rigid crust plays in influencing lava flow and morphology once cooling initiates. Linear and exponential models for $\nu(t)$ will be explored, and once solutions have been established, the range of boundary conditions in r_o and h_o for which the solutions are valid will be determined. Model constraints will be provided by the dimensions of several specific Venus domes, (e.g. Fig. 1), as well as by initial viscosities for a range of magma compositions.

Questions still arise as to whether the rheology of europan cryolavas would be amenable to relaxation to form domes in physically realistic timescales [7], and if europan domes are indeed the products of radial effusions of lava from a central vent rather than the surface expressions of diapirs that breached the surface and subsequently relaxed, giving the illusion of having been produced by cryolava flows [5,7-8,16]. Applying this model, with viscosities suggested by [7] and [17], to the emplacement and relaxation of effusive cryolava domes on Europa would provide answers to these questions by allowing estimates of dome viscosities to be made and their compositions to be better constrained. The results of these models will have significant implications for subsurface conditions and processes that can sustain such conditions on both planetary bodies.

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