MODELING OF STEEP-SIDED DOME FORMATION ON VENUS. J. Fang[1, 2], W. Tian[1], L. Wang[1], W. Fa[1] and X. Liu[1], [1]School of Earth and Space Sciences, Peking University, Beijing 100871, China, [2]Yuanpei College, Peking University, Beijing 100871, China. (fjq@pku.edu.cn, davidtian@pku.edu.cn)

Introduction: Steep-sided domes on Venus display unique topographic and morphologic features and they have been measured and analyzed in prior studies [1, 2]. It was noted that the domes could be related to viscous magmas effused from central conduits [3]. And their almost perfect roundness implies a single effusion event. Based on those assumptions, we designed a numerical model to simulate the formation process of such domes. Particularly, we quantified the effects of viscosity, temperature and effusion rate of lava flows on dome shapes.

Numerical Model: Our computer project adapts the model of Bilotta et al. [4] to Venusian environment with tailored modifications. Lava flows are modeled as Bingham fluids so a steady state solution to Navier-Stokes equation can be employed to get magnitudes of flows. A cellular automation approach [5] is used to simulate spread of lava flows with a Monte-Carlo algorithm solving the problem of anisotropic flow directions for square cell grids. Parallel calculations via CUDA are executed to promote computational efficiency.

To ensure better veracity of simulations, several optimizations are made by us. The heat transfer area of a grid is greater than the square of grid width due to elevation differences from neighbors so a correction should be performed. In addition, the dense CO_2-rich Venusian atmosphere has strong absorption in the infrared. Radiative and convective heat fluxes can thus get coupled when lavas are cooling on the surface of Venus. We calculated coupled heat fluxes with absorption data from HITRAN-16 Database and implemented them into our model to replace simple decoupled ones [6, 7].

Parameter Setting: Environmental parameters specific to Venus are applied, including gravity (8.8 m/s^2), air temperature (750 K), air density (65 kg/m^3) and air pressure (9.2 MPa). In the meantime, we selected three typical viscosity-temperature curves (Figure 1) for simulations, representing properties of acidic, intermediate and basic lava flows, respectively [8, 9, 10].

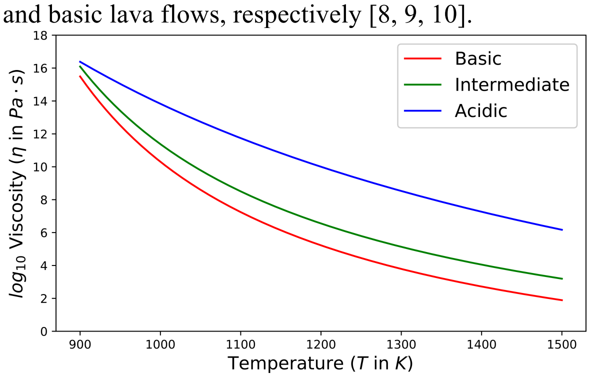

Figure 1: Viscosity-temperature curves of three different lava types.

Method Design: We tested all the three curves (Figure 1) in our model and compared dome diameters and heights calculated by it with those in topographic data measured by Magellan Radar. Viscosity-temperature correlations making the two consistent are chosen for further investigation.

Effusion rates are preliminarily constrained before experiments. Many observed Venusian domes have volumes over 100 km^3. Considering lava flows are unlikely to keep effusing from a conduit for years or longer, we deduce only effusion rates greater than 10^4 m^3/s are reasonable. Plus, effusion rates exceeding 10^7 m^3/s can be rare based on practical experience. So in our simulations, lava flows would effuse from a central vent at a constant rate ranging from 10^4 to 10^7 m^3/s for a certain time span. Furthermore, given conceivable influence of extrusion temperature, two groups of experiments were done, one initialized at 1300 K and the other at 1200 K.

Our simulation results are compared with real topographic data. Then we are able to estimate value ranges of effusion rate and extrusion temperature that can form steep-sided domes on Venus.

Results: Evolutions of dome shape parameters, such as height and diameter, manifest a similar tendency over their growth and relaxation periods. During effusion of lava flows from the central vent, dome height and diameter keep increasing. At the relaxation stage, magma supply from the central vent stops and the dome becomes lower while its diameter continues increasing. The eventual morphologies of domes calculated by our model are consistent with measured ones (Figure 2).

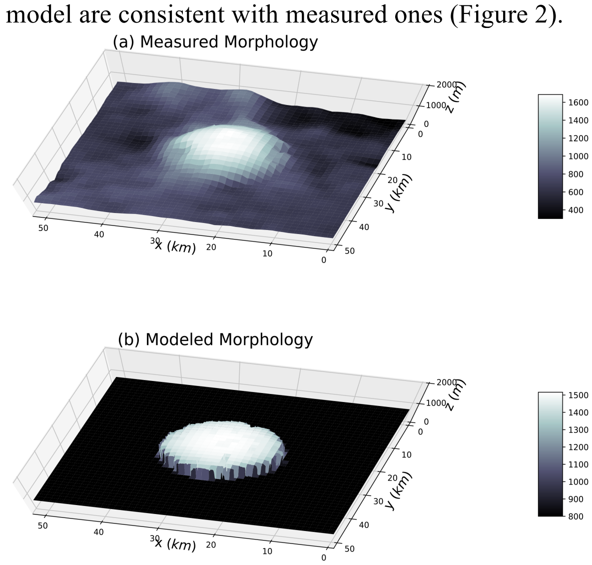

Figure 2: Morphology of a dome from Magellan Radar topographic data (a) and morphology of a dome calculated by our model (b).

We verified the importance of lava types (Figure 1) suggested in previous work [1, 3]. It shapes the dome by determining the correlation between viscosity and temperature of lava flows. High-viscosity lava flows can form domes with relatively large heights and small diameters (Figure 3).

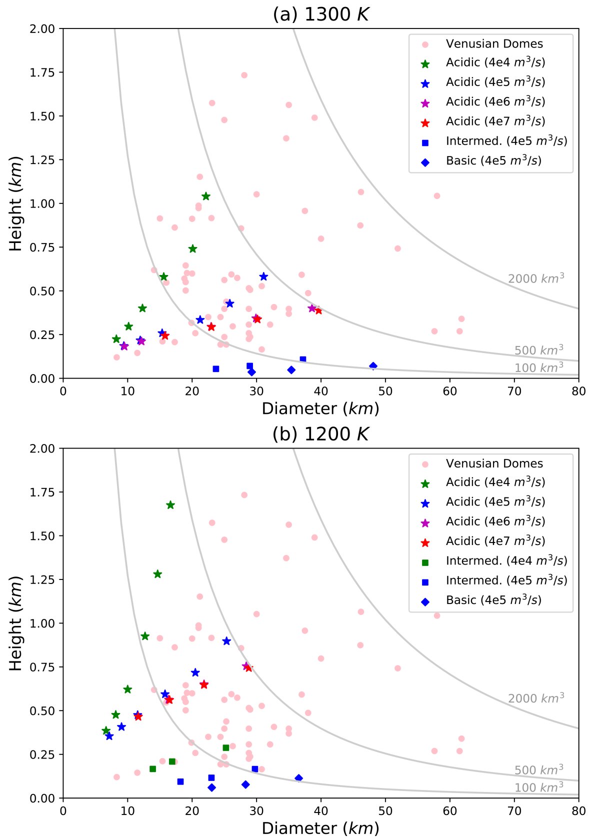

Figure 3: Shape parameters of domes in simulation results with different viscosity-temperature correlations, effusion rates and extrusion temperatures of lava flows, compared to those in Magellan Radar topography on Venus.

With an extrusion temperature of 1300 K and an effusion rate at an order of magnitude between 10^4 and 10^6 m^3/s, acidic lava flows can reproduce most (> 80%) observed dome morphologies, while basic and intermediate lava flows fail to accomplish it (Figure 3a).

When lavas effuse at 1200 K, heights and diameters calculated for acidic domes can only partially (< 40%) overlap measured dome shape parameters. Meanwhile, intermediate lava flows with low extrusion temperature and effusion rates may be relevant to other domes with lower aspect ratios (Figure 3b).

Besides viscosity-temperature curves, effusion rates and extrusion temperatures of lava flows can exert crucial effects on dome shapes as well. With effusion rate increasing or extrusion temperature decreasing, domes formed are horizontally smaller and vertically higher (Figure 3). However, when effusion rates are large enough, for example, having reached 10^6 to 10^7 m^3/s, variation of the final dome shapes is negligible.

Discussions: The viscosity differences among lavas during their flowing and cooling processes can account for shape distinctions. The impact of viscosity-temperature curve types is evident. Moreover, a smaller effusion rate or a lower temperature of extrusion, indicating higher lava viscosity in the flowing process, gives rise to more difficulty for lava flows to spread. Hence a horizontally smaller and vertically higher dome is generated.

After comparisons, we assume 1200 ~ 1300 K and $10^4 \sim 10^6$ m^3/s are appropriate estimations of extrusion temperatures and effusion rates of lava flows that form the domes.

Our model has made new constraints on the effusion rates of lava flows that can form steep-sided domes. Measurement of researchers in the past showed effusion rates for terrestrial effusive volcanoes could be no more than 10^4 m^3/s [11, 12]. Our estimation for Venusian steep-sided domes is remarkably greater than those terrestrial values, which may also explain their larger volumes. There are some other experimental studies that concentrated on diverse extraterrestrial volcanism and confirmed large effusion rates might be necessary for acidic lava flows to form Venusian steep-sided domes [13]. The divergence between effusion rates may reflect discrepant geodynamic settings for volcanisms on Venus and Earth.

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