VENUSIAN VOLCANO SHAPES: IMPLICATIONS FOR EDIFICE EVOLUTION AND THE INTERNAL THERMAL STATE OF VENUS. J. Buz[1] and P. McGovern[2], [1]Massachusetts Institute of Technology Department of Earth, Atmospheric, and Planetary Sciences (jbuz@mit.edu), [2]Lunar and Planetary Institute, USRA (mcgovern@lpi.usra.edu).

Introduction: Radar imaging and topography data from the Magellan mission to Venus revealed over 150 volcanic edifices with diameters in excess of 100 km [1,2,3]. Most of these edifices exhibit conical or domical topographic profiles. However, several volcanic constructs are annular in shape, falling into the morphological category "corona" [e.g., 4,5]. Recently, a link has been proposed between volcanic edifice shape and the thickness of the elastic lithosphere (T_e), based on the predicted effects of lithospheric stress on magma ascent [6,7]. Such a link could allow us to place constraints on the thermal evolution of regions on Venus.

Using Magellan radar backscatter images and topography data, we have isolated shape characteristics of some volcanoes such as shape and flow length. These constraints can be used for automated detection of class (conical, domical, or annular) based on topographic data. Furthermore, we have used a model for volcano growth that links magma ascent with lithospheric flexural stresses, to create a suite of potential volcanoes influenced by magma source dimensions and supply rate, and T_e. After fitting of model volcano topography with actual volcano topography, a set of parameters are inferred for each volcano. This allows for local determination of T_e, which can be applied to infer variations in thermal history over larger regions of Venus.

Data: We have been using radar backscatter images and topographic data of Venus acquired by Magellan in the 1980s and made available by the USGS online [8]. In addition to the raw topography data we are also using topography filtered by best-fit planes along 40- and 80-km baselines.

Methods: We model volcano growth in a self-consistent manner, calculating the interaction of the lithospheric stress state and magma ascent. In each model, a characteristic magma source radius (r_m) and central height (h_m) are defined. Magma distribution is then subdivided into a number n_{inc} of equal height increments (values adopted: 1, 5, 10, and 20). The n_{inc} parameter reflects a relationship between the magma supply rate and the characteristic flexural response time of the mantle asthenosphere, or Maxwell time τ_M. High n_{inc} corresponds to relatively low magma supply rate and vice versa. For a given stress state, magma ascent at a given location depends on two criteria [6]: favorable horizontal normal stress orientations (horizontal extension [9]) and gradients (extension increasing upward [10]). Our model evaluates these criteria as functions of radius r at a discrete set of points. At points where both ascent criteria are satisfied, the magma height for the current increment is added to the surface load; at points where one or both criteria are violated, the magma is diverted to the closest point where ascent is allowed, and distributed to adjacent points within a characteristic width (here taken to be 25 km). The new load distribution is then applied to the lithosphere, a new stress state calculated, and the cycle is repeated n_{inc} times

We average a volcano's topography in annular bins to create a smoothed radial topography profile. Then, we cycle through all possible model volcanoes and do a least squares fit of the model volcano's profile with the actual volcano's profile. We also match maximum slope and radius of the maximum slope of the annularly averaged topography on the edifice with those of model volcanoes. Though the model volcanoes found using this method might not be the best match as determined by the least squares fit of the entire topography, the model volcanoes returned usually have the same edifice shape as the actual volcanoes.

Results: A few trends in volcano evolution have been observed. Figure 1 shows variations of final edifice shape as functions of elastic lithospheric thickness T_e and magma source radius r_m. In general, lower values of T_e and higher values of r_m favor the generation of annular volcanoes. Cones are found mostly at the lowest value of r_m shown, except at the highest T_e value. Domical shapes are found in a narrow stretch of parameter space between conical and annular regions. Low values of magma source central height h_m and number of increments n_{inc} favors formation of conical edifices; increasing these parameters tends to lead to more domical and then annular edifices. The evolution of individual edifices over many load increments shows that many eventually non-conical edifices have conical shapes in their early stages; at some point, high adverse stresses and stress gradients in the central regions shutoff magma ascent there, leading to favored lava emplacement on the mid flanks. This cutoff causes a transition to domical edifices at first, then annular if the process continues.

Figure 2 shows the best fit model volcanoes for the actual volcano Kali Mons (9.4N 29.75E). The left most image is the model volcano best fit for topo-

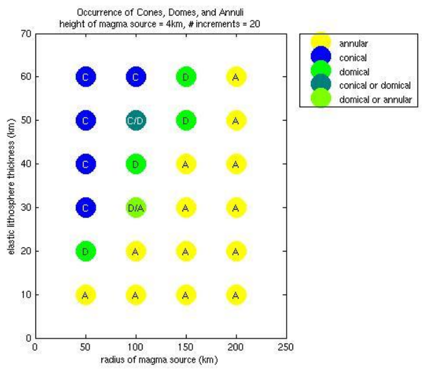

Figure 1
Distribution of conical (C, blue), domical (D, green), and annular (A, yellow) edifices as functions of magma source radius r_m and lithospheric thickness T_e.

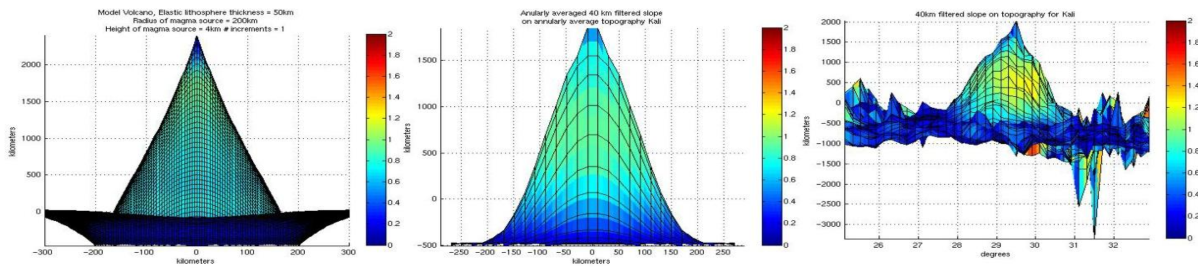

Figure 2.
3-D representations of slope (colorscale) draped over topography (vertical relief) for (a) best-fit model; (b) annularly averaged edifice, and (c) actual edifice, for Kali Mons.

graphy and slope, the middle image is the annularly aver- aged topography for Kali Mons with the colors representing the annularly averaged slope data. The right most image is the 40km filtered slope of Kali Mons over the actual topography. The model provides satisfactory fits to the height, width, shape, and slope data for the edifice. We conclude that Kali Mons was emplaced on a thick lithosphere (T_e = 50 km), with relatively large magma source (r_m = 200km, h_m = 4km), and took place relatively quickly (n_{inc} = 1).

Discussion: We suggest that the diversity of volcanic edifice shapes on Venus is due to changing stress conditions which cut off magma ascent. Annular edifices arise from weak or thin lithospheres, long emplacement times (coupled with more increments of magma emplacement), and larger magma source widths. Flexural rigidity is proportional to T_e to the third power, for this reason small increases in T_e help to maintain conical edifices. Broader loads (or, magma sources) are more likely to form corona-like structures at a given T_e, as previously predicted [3]. The lithosphere deforms more readily as the radius of the magma source increases and therefore generates more stress for a given amount of magma. The greatest stress state is in the center of the edifice where the most magma is emplaced.

Central ascent cutoff is what drives magma ascent to the outside of the edifice forming domes and eventually annuli (coronae). Fast emplacement of lavas more often yields conical edifices because of a delayed response time of the lithosphere to the stresses. The lithosphere might not be able to flex in the amount of time a few lava eruptions take place, therefore those eruptions are essentially taking place on a straight flat rigid lithosphere. The lava flows observed in the radar backscatter images sometimes show what appear to be lava flows traversing upslope. Our intuition tells us that these topographic rises must post date the flows. Therefore, the volcano (flexurally) subsided after the lavas were erupted.

A look at the regional distribution of domes, cones, and annuli in the northern hemisphere of Venus gives hints as to the regional thickness of the lithosphere. The northern Atla region is remarkably volcanically active, with a even distribution of domes and cones. Based on our results for the requirements for these shapes of edifices we can conclude that this region has either a thick, strong lithosphere or that the volcanoes in this region have a faster supply rate than in other regions. We favor the former hypothesis because of the lack of compressional faults observed. If the volcano was erupted onto the surface in a time shorter than the Maxwell time, and afterwards the lithosphere flexed, there would be more faults than if it were a gradual process [e.g., 11].

References:

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