REPRODUCING VOLCANIC EVENTS ON VENUS USING MAGMA RESERVOIR FAILURE MODELS.

S.M. Long[1], D.M. Hurwitz[1], E.B. Grosfils[1] and P.J. McGovern[2]. [1]Geology Dept., Pomona College, Claremont, CA 91711 (sylvan.long@pomona.edu). [2]Lunar & Planetary Institute, Houston TX

Introduction: Intermediate and large volcanoes on Venus have a similar structure to the largest volcanoes on Earth, with tall central edifices around 2 km in height and broad, gradually sloping flanks at least 50 km in radius [1]. The planet's volcanic history also includes numerous dike swarms. The dikes range in length from 10s to 1000s of km, and many radiate from magma centers; at some locations these centers also include a volcanic edifice [2]. The dikes are inferred to form when rupture of a shallow magma reservoir promotes lateral propagation of magma in a vertically oriented fissure (dike) instead of a horizontally oriented fissure (sill).

Previous analytical and numerical models of the stresses involved in magma reservoir rupture, both excluding and including an overlying edifice, predict lateral dike formation [e.g., 3,4]. However, a recent half-space finite element model (FEM) has been used to demonstrate that this result is erroneous because published models do not correctly incorporate full gravitational loading of the host rock [5]. The revised model corrects for this problem and predicts that failure near the crest of a reservoir will yield vertical dikes or circumferential intrusions, while failure near the mid-depth of the reservoir promotes lateral sill formation but not lateral dikes.

The current mapping and FEM study uses the model of [5] and edifice loading modifications described in [6] to explore whether simple elastic models of reservoir failure can reproduce the volcanic stratigraphy observed at two different intermediate volcanoes on Venus.

Methods:

Mapping. Magellan radar backscatter and physical property data (GxDR) were overlaid in ArcGIS and used to map two volcanoes and constrain their volcanic stratigraphy. Eight radial profiles were used to define an average conical topography section employed when modeling each edifice.

Model setup. COMSOL Multiphysics software was used to produce 2D, axisymmetric, elastic half-space FEMs with a conical edifice overlying a spherical magma reservoir. The half-space size was set to 600x600 km in order to avoid edge effects. The half-space constraints allow no vertical displacement of the bottom boundary and no radial displacement of the outer boundary. The upper host rock boundary and edifice were left free to deform. Material properties (e.g., Young's Modulus) of the host rock and edifice were given values equivalent to those of [5]. The host rock and edifice were then gravitationally loaded in a lithostatic stress state. The reservoir boundary was loaded with depth-dependent magma weight plus a uniform magma pressure term, both applied normal to the reservoir wall. As noted in [6] failure was produced by iterating the magma pressure (P) until the stress tangential to the reservoir wall within a vertical (σ_t) or horizontal (σ_{phi}) plane exceeded the tensile strength limit (TSL) of the host rock. The failure location was measured using the angle (α) between a line through the center of the reservoir and the failure location and a horizontal line through the center of the reservoir (i.e. $\alpha = 90°$ represents failure at the crest).

Model runs. The primary variables tested were edifice height (H_e) and radius (R_e), the reservoir radius (R), and the depth from the half-space surface to the center of the reservoir (DtC). For each of the edifices, the R/DtC ratio was varied either by changing R while holding DtC constant, or vice versa. The R values used ranged from 1.5 - 6 km, reflecting observed caldera dimensions, while the DtC values ranged from 3.5 - 11 km to isolate the primary effects of the scaled reservoir size/depth on failure location. Finally, a few models examined an oblate rather than spherical reservoir.

Results and Discussion:

Mapping results. Basic volcanic stratigraphy is inferred using the geologic units mapped on each volcano. Edifice A (Figure 1A) experienced an initial period of radial dike injection, followed by central eruptions and edifice growth before ending with further radial dike formation. Edifice B (Figure 1B) experienced central eruptions and edifice growth, then radial dike formation, and ended with further lava flow emplacement.

Modeling results. For a spherical reservoir, initial rupture consistently occurs in the σ_t orientation and failure occurs at or near the crest (i.e. $\alpha > 66°$). Models using gently oblate ellipsoidal reservoirs indicate that σ_t continues to rupture before σ_{phi} and failure occurs at or near the midpoint of the reservoir (i.e. $\alpha < 32°$).

As R/DtC varies, Edifice A displays changes in failure location similar to those observed with no edifice present (Figure 2). Increasing R/DtC causes failure to migrate from the crest down to slightly greater depths before moving back towards the crest. This is consistent with the free surface effect identified by [5], where the proximity of the free surface causes deeper rupture. Reservoirs beneath edifice B consistently rupture at their crests, suggesting that the larger edifice load/height reduces any free surface effect.

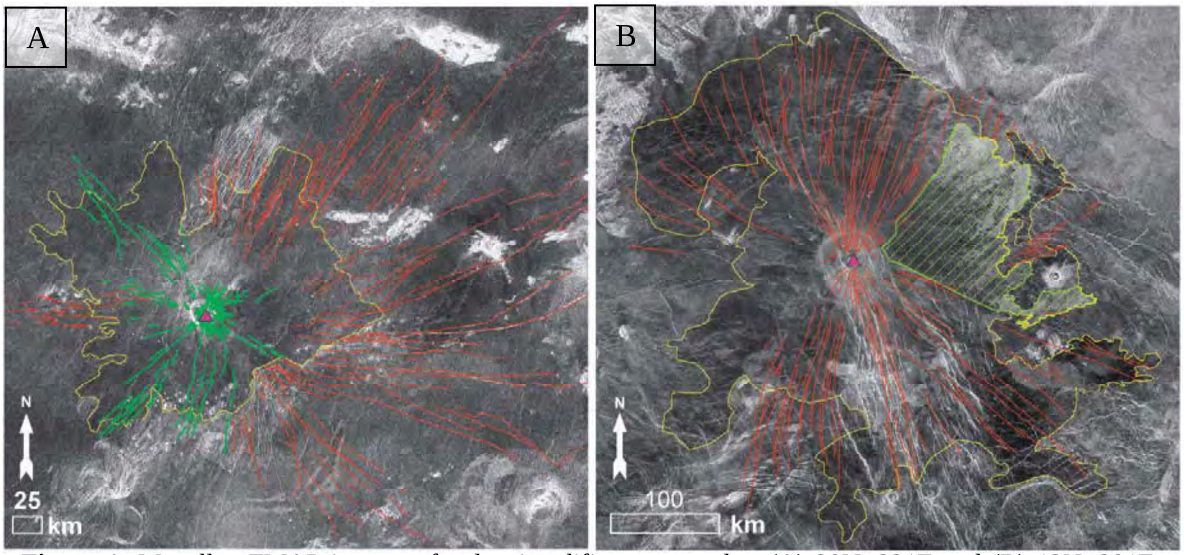

Figure 1: Magellan FMAP images of volcanic edifices centered at (A) 29N, 221E and (B) 13N, 291E. Mapped geologic units are interpreted to have formed through separate periods of activity. See text for stratigraphy details. Red lines = first radiating dikes, green lines = second radiating dikes, yellow boundary = edifice-derived flows, green boundary with pattern = younger flows, triangle = central vent.

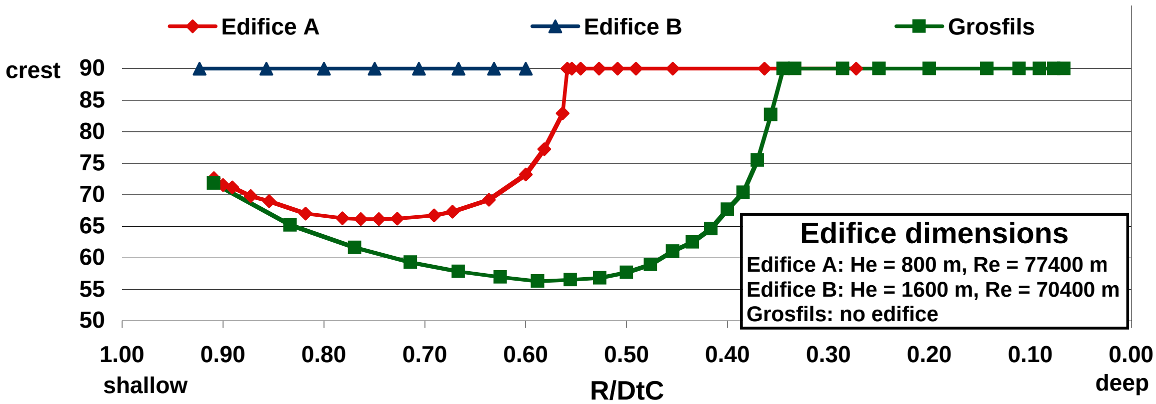

Figure 2: Effect of edifice dimensions on rupture location. All ruptures occur in σ_t orientation.

The edifice loading effects identified support and supplement the results of [6]. Figure 2 shows that the presence of an edifice generally produces shallower rupture than when an edifice is absent [5]. To a first order, a taller edifice amplifies this effect. The effect of an edifice is not equivalent to increasing the DtC beneath a flat surface, however, as is demonstrated by the changing shape of the lines in Figure 2.

The conditions promoting vertical magma ascent, and hence edifice-constructing eruptions, occur when either larger edifices and/or deeper reservoirs are present. Lateral dike propagation, however, is only promoted if initial failure of the reservoir near its mid-depth occurs in the σ_{phi} orientation. This condition is never achieved, indicating that no plausible changes within the parameters considered, including the addition of an edifice load, will produce lateral dikes.

Conclusion: Elastic tensile failure models using internally pressurized ellipsoidal reservoirs and proper gravitational loading are unable to reproduce some commonly observed volcanic features. Specifically, because failure conducive to lateral dike injection does not occur, such models cannot explain even the simple stratigraphy of the two Venusian volcanoes mapped here. Our results challenge previous contentions about the ability of reservoir failure models to promote lateral dike injection [e.g., 3,4], and demonstrate that other factors/conditions (e.g., stresses from lithospheric flexure [7]) must be considered to understand volcano growth on Venus.

References: [1] Crumpler L.S. and Aubele J.C. (2000) *Encyc. of Volc.*, 727 – 770. [2] Grosfils E.B. and Head J.W. (1994) *GRL*, 21, 701-704. [3] Pinel V. and Jaupart C. (2004) *Earth & Plan. Sci. Let.*, 221, 245-262. [4] Parfitt E.A. et al. (1993) *JVGR*, 55, 1-14. [5] Grosfils E.B., *JVGR*. submitted 2006 [6] Hurwitz D.M. et al. (2007) this volume. [7] Rumpf M.E. and McGovern P.J. (2007) this volume.

Acknowledgements: This project was jointly funded by NASA grant NNG05GJ92G and by a Summer Undergraduate Research Project grant from Pomona College.