STRAIN AS AN INDICATOR OF MULTIPLE EPISODES OF UPLIFT AND EXTRUSION AT RADIALLY-FRACTURED CENTERS ON VENUS. P. M. Grindrod[1], F. Nimmo[2], E. R. Stofan[1,3] and J. E. Guest[1], [1]Department of Earth Sciences, University College London, Gower Street, London, WC1E 6BT, UK (p.grindrod@ucl.ac.uk), [2]Department of Earth and Space Sciences, University of California, Santa Cruz, USA, [3]Proxemy Research, Laytonsville, MD, USA.

Introduction: Radially-Fractured Centers (RFCs) are distinctive ~1000 km-long radiating systems of graben, fissures and fractures usually arranged around a central topographic high [e.g. 1-3]. Two interpretations have been proposed for the formation of RFCs: (a) sub-surface dyke propagation at shallow depths causing radial fracture patterns at the surface [1-4]; and (b) surface uplift caused by the impingement of rising mantle diapirs during the corona-forming process [e.g. 5-8]. However it is likely that RFCs are a combination of both processes, with fractures due solely to uplift being less abundant and more centrally located than those associated with dyke emplacement [3].

This paper focuses on those radial graben which are interpreted to be the result of uplift alone. We studied four RFCs: Dhorani Corona (8°S, 243°E), Lengdin Corona (2.5°N, 223°E), Mbokomu Mons (15.1°S, 215.2°E), and Pavlova Corona (14.3°N, 38.9°E). At each RFC we identified graben which are typically several kilometers wide near the summit region and decrease in width significantly with increasing distance from the central region (Fig. 1). We measured the strain recorded on these graben as a function of distance from the center, and modeled this strain in terms of uplift caused by the inflation of a spherical magma body at depth.

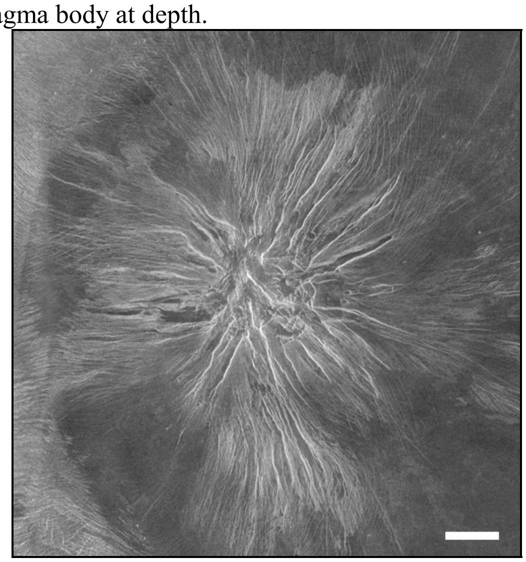

Figure 1. Example of the RFC at Pavlova Corona showing several large, radial graben located close to the central region. Scale bar is ~ 40 km.

Strain Measurements: The strain at the RFCs is assumed to be accommodated by several major radial graben, and can be estimated by determining the amount of extension at the graben. The minimum extension recorded at each graben is the amount needed to account for the current width of the walls, assuming that the extension is accommodated by normal faults. To determine the extension, the width and depth as a function of distance along the graben were measured. Depth measurements were obtained by using the incidence properties of the active radar system on Magellan and assuming a symmetrical normal fault [9]. The total hoop strain accommodated at a RFC as a function of distance from the center was calculated by summing the extension measured at all graben and dividing by the circumference around the RFC at a given distance:

$$\varepsilon(r) = \frac{\sum \Delta W(r)}{2\pi r} \quad (1)$$

Strain and Uplift Modeling: We modeled the strain at the surface as the result of uplift caused by a pressurized spherical cavity in an elastic half-space [10]. In this model the hoop strain can be shown to be given by,

$$\varepsilon_h = \frac{2Pe^3}{E}\left[\frac{(1-\upsilon^2)}{(\rho^2+1)^{3/2}}\right] \quad (2)$$

where P is the pressure increase in the sphere, e is the ratio of sphere radius, a, to depth to the center of the sphere, f, E is Young's modulus, υ is Poisson's ratio, and ρ is the radial distance, r, divided by f.

The modeled hoop strain can thereby be determined as a function of r and compared to the hoop strain measured at the RFCs. P is set at a constant value of 200 MPa [11], and we then solve for the best fit of a and f. Vertical displacements can be determined using the values of a and f, which are then used to determine the topography prior to the inflation-related uplift inferred from the graben.. Topographic volumes were calculated by fitting a Gaussian curve to the pre and post-uplift profiles, and then determining the volume of revolution about the height axis for a given radius at each RFC. Parameter ranges are those values that lie within 1.5 times the minimum misfit value, H [12].

Results: The overall strain distribution is similar at each RFC. Maximum strain is recorded at the center of the RFC, and decreases asymptotically to zero with increasing distance from the center. Strain at the center is greatest at Dhorani Corona, which also has the shallowest sphere depth. The maximum strain values at the other RFCs are more modest, all being less than 0.5%. The strain is effectively zero at a distance of about 40 km in most cases; Pavlova Corona is the exception with strain close to zero at a distance of greater than 70 km (Fig. 2). Sphere radii vary between about 10 and 29 km; larger values corresponding with greater depths. All depths returned are less than the radii of the spheres, indicating that they have not penetrated the surface. The depth to the top of the sphere (*f*-*a*) varies between about 2 and 7 km, with none entering the topographic edifices.

There is a very small amount of volume increase recorded at each RFC. Pavlova Corona shows the largest volume increase with an increase of about 13% (Fig. 2); the other RFCs show significantly smaller increases, being 1 or 2 orders of magnitude less. This indicates that the radial graben record only small amounts of uplift. This is confirmed by the maximum change in height which is of the order of about 100 m or less at each RFC, apart from Pavlova Corona which shows an uplift of about 200m. From the radially-averaged topography, the pre-uplift topographic profiles of Dhorani and Lengdin Coronae show central depressions of up to ~ 25 km in radius, and ~ 60 and 600 m in depth respectively.

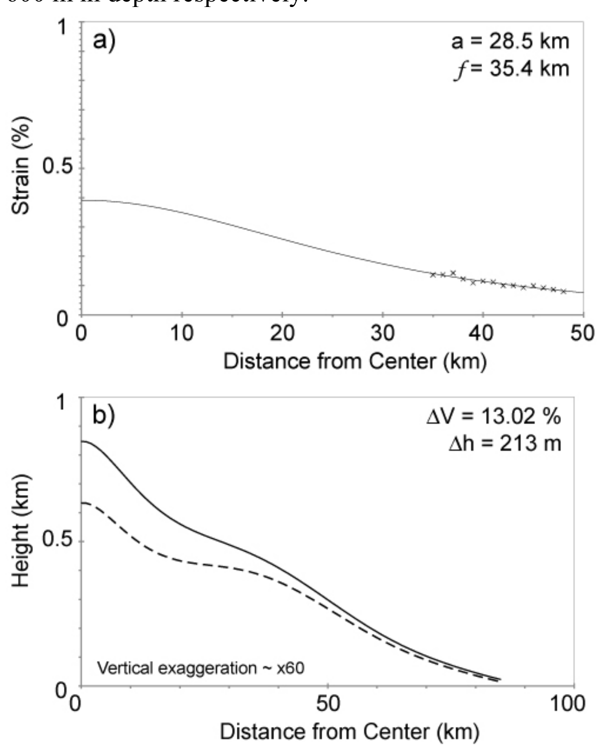

Figure 2. Example results for Pavlova Corona. (a) is the measured hoop strain (crosses) compared to the model (solid line), (b) is the present-day topography (solid line) compared to the inferred pre-uplift topography (dashed line). ΔV is the volume change, Δh is the maximum amount of uplift.

Table 1: Best fit and parameter range for magma chamber radius, *a*, and depth, *f*. *H* is the misfit.

RFC	Best Fit *a* km	Range (H=1.5) *a* km	Best Fit *f* km	Range (H=1.5) *f* km
Dhorani Corona	9.6	9.3 - 10.0	11.5	9.8 - 13.8
Lengdin Corona	11.5	11.0 -12.1	15.0	12.1 – 17.7
Mbokomu Mons	13.1	12.2 – 14.1	17.6	13.6 – 22.1
Pavlova Corona	28.5	25.9 – 32.1	35.4	27.5 – 44.8

Conclusions: We have used the strain observed at large radial graben located close to the center of RFCs to estimate the amount of uplift that has occurred as a result of inflation of a spherical magma chamber. The relatively low-levels of strain indicate that either (a) the majority of the topography at RFCs is not due to uplift alone, requiring a significant volcanic construction contribution, or (b) previous episodes of uplift have been buried by lava flows, suggesting episodic activity. It is most likely that both are true to different extents throughout the evolution of the RFCs. Further evidence of repeated episodes of uplift and extrusion is identified by the insufficient magma chamber volumes needed to account for the surface topography. We have modeled the strain in terms of a spherical magma body at depth. The radius of the sphere modeled at each RFC is consistent with measurements of RFC caldera size. This model of uplift accounts for the strain at large radial graben whilst also providing a source for continued radial dyke propagation.

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