TOPOGRAPHIC CHANGE RECORDED BY LAVA FLOWS AT CORONAE ON VENUS: EVIDENCE OF EVOLUTIONARY COMPLEXITY. W. S. Tucker[1] and A. J. Dombard[1], [1]Department of Earth and Environmental Science, University of Illinois at Chicago, 845 W. Taylor St., Chicago, IL 60607 (wtucke5@uic.edu).

Introduction: Coronae are volcano-tectonic features on Venus initially characterized by their concentric fractures and ridges [1]. Analyses using Magellan SAR and altimeter data have shown coronae surface characteristics to be varied in the amount of concentric faulting, topographic signatures, diameters, and extent of associated volcanism [2, 3]. Geophysical models of corona formation have been able to reproduce only some of the features associated with corona, and most models have difficulty capturing more than one or two characteristic observations. One interpretation produces coronae from a buoyant mantle diapir with a diameter approximately equal to that of the resulting surface expression [4-6]. Other models have attributed coronae to downwelling of the lithospheric mantle [7], crustal loading from partial melt at the head of an impinged thermal [8], or stress-regulated volcanic construction [9].

A "standard model" of corona evolution that results from a thermally buoyant diapir has three main stages [10]. First, a rising mantle diapir causes an initial domical uplift. Then, as the diapir impinges on the lithosphere, it flattens and spreads radially creating a plateau in place of the domical feature. Last, as the diapir cools, the surface relaxes forming an interior depression. It has been suggested that the various topographic signatures observed among coronae are evolutionary stages from domal to circular to calderic with two transitional stages [11]. Additionally, detailed mapping of coronae in Guinevere and Sedna Planitia has shown a complex evolution with multi-stage annulus formation [12].

The role of volcanism in corona formation and evolution is unclear, and only a limited number of coronae have any associated volcanism [e.g., 13]. For those coronae with associated volcanism, though, the scale is often comparable to that of terrestrial flood basalts [14]; therefore, intrusive and extrusive magmatism has the potential to be significant during and after the formation of coronae [e.g., 8, 9]. Volcanism is thought to occur during the domical uplift stages before shifting to extra-annulus volcanism as the concentric fractures form and again shift towards the interior during the last evolutionary stage [10]. Although the degree of volcanism for each stage is difficult to discern, exterior volcanism during annulus formation appears to be more extensive than the interior volcanism of the first and final stages [11].

The relationship between volcanism and corona evolution might be revealed by comparing flow directions to modern topography, as lava flows have the ability to inform how topography may have changed since the flows were emplaced. The downhill direction of a lava flow is recorded in its morphology and the relationship among flow units, irrespective of any topographic data [e.g., 15, 16]. Any topographic change that has occurred since the time of flow emplacement will be recorded in the difference between the topographic and flow directions. In this study, we briefly assess the degree of volcanism within coronae, and apply paleotopographic techniques to lava flows associated with the coronae, focusing on Atete Corona (16°S, 243.5°E), with particular attention paid to its intra-annulus flow units.

Methods: Using Magellan SAR images (75 m/pixel) imported into ArcGIS 10.6, a global survey of lava flows associated with coronae is conducted from catalogs of Type 1 and Type 2 coronae [2] and those recognized in the USGS Venus nomenclature database (planetarynames.wr.usgs.gov). Favorably stretched SAR data allow for identification of discrete lobate and digitate flows [e.g., 17]. Where sufficient corona associated lava flows are identified, individual flow units are mapped and their azimuthal orientation is calculated from their geographic start and end points. A buffer with a 15 km radius is processed at the midpoint of each flow unit, and a mean regional slope direction is calculated from an aspect raster derived from Magellan altimeter data for the area of the buffer. The differences between the regional slope direction (mean aspect angle) and the direction of the flow unit (azimuthal orientation) reveals the angular differences that resulted from topographic change since the flow was emplaced.

Results: A total of 545 unique coronae are identified in the two corona databases, of which 13% have discernable volcanic flows within their fracture annuli. However, only 7% have lava flows with mappable units. For the 40 coronae with mappable lava flows, 9 have substantial topographic change along flow paths. An additional 10 show evidence of topographic change, but are limited by too few or too short mappable flow units.

Atete Corona is the clearest example and has extensive lava flows both within and outside of its annulus. Mapping of the interior flows show most lava flows appear to flow uphill (Fig. 1). Flows are seen radiating from an edifice in the southern part of the corona extending to the northern limit of the concentric fractures. Exterior lava flows at Atete Corona also indicate topographic change since the emplacement of some flows. Flows to the east of the annulus indicate counterclockwise rotation of the slope face (Fig. 2).

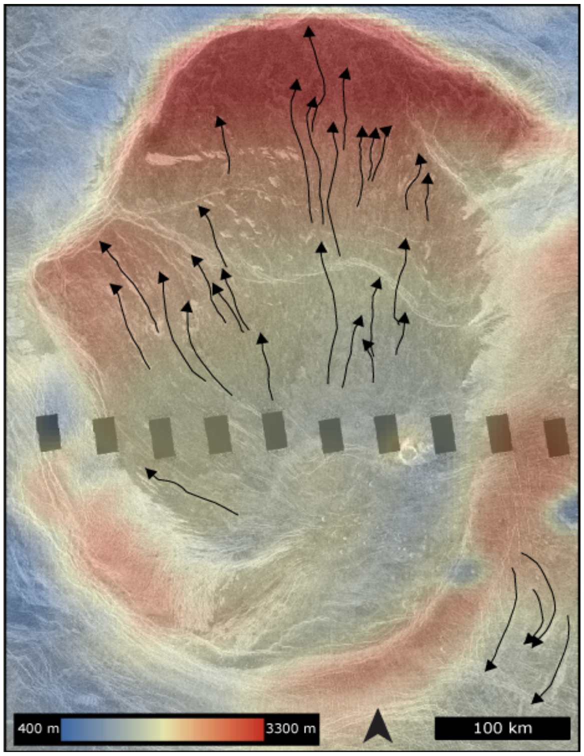

Figure 1. Topography of Atete Corona (16°S, 243.5°E) overlying Magellan SAR image with black arrows indicating apparent flow direction of mapped lava flows.

Discussion: Mapped lava flows within the fracture annulus of Atete Corona show marked difference between their original direction of flow and the current topographic gradient. The source of these interior flows appears to be a region of radial fractures near the southern corona rim. Many corona models indicate domical uplift and radial fracturing as an early or first stage of evolution [e.g., 3]. This early stage is consistent with the results found here, where the formation of the fracture annulus and topographic rim led to the current orientation of the slope face and uphill lava flows. Notably, this early center is not in the geographic middle of Atete.

The flows on the exterior of Atete show less change of the topography than is observed in the interior. Here, redirected flows intermingle with flows that follow the modern slope. This finding suggests multiple volcanic events with younger flows found on the flanks of the corona. All interior flows being redirected while only some on the exterior suggests the interior flows are relatively old, while the exterior flows show a range of ages, though cross-cutting relationships are generally lacking to test this hypothesis directly. The progression of volcanism to the annulus is consistent with lithospheric loading via constructive edifice growth [18].

These findings suggest why models have difficulty capturing more than one or two characteristic observations: coronae, like most geological features, are messy and do not exactly follow textbook models of formation and hence show a range of deviations from these schematic models. The northward surface inflation and extension of the annulus from an initial center violates the axisymmetry of these simple models. What is clearer is that volcanism played a significant role in this evolution, though improved imagery and topography are needed to test these ideas further.

Acknowledgments: This research was supported by the Illinois Space Grant Consortium. We thank S. Smrekar for her vast insight.

References: [1] Barsukov V. L. (1986) *JGR, 91*, 371-398. [2] Stofan E. R. et al. (2001) *GRL*, *28*, 4267. [3] Glaze L. S. et al. (2002) *JGR*, *107*, 5135. [4] Janes D. M. et al. (1992) *JGR, 97*, 16055-16067. [5] Koch D. M. & Manga M. (1996) *GRL*, 23, 225-228. [6] Smrekar S. E. & Stofan E. R. (1997) *Science*, *277*, 5330. [7] Hoogenboom T. & Houseman, G. A. (2006) *Icarus*, *180*, 292-307. [8] Dombard A. J. et al. (2007) *JGR*, *112*, E04006. [9] McGovern P. J. et at. (2013) *JGR*, *118*, 2423-2437. [10] Squyres S. W. et al. (1992) *JGR*, *97*, 13611-13634. [11] DeLaughter J. E. & Jurdy D. M. (1999) *Icarus*, *193*, 91-83. [12] Copp D. L. et al. (1998) *JGR*, *103*, 19401-17417. [13] Martin P. et al. (2007) *JGR*, *112*, E04S03. [14] Roberts K. M. and Head J. W. (1993) *GRL*, *20*, 1111-1114. [15] Chadwick J. et al. (2015) *JGR: Planets*, 120, 1585-1595. [16] Mouginis-Mark P. J. & Wilson L. (2019) *Icarus*, *319*, 459-469. [17] Zimbelman J. R. (2003) *JGR*, *105*, 5043. [18] McGovern P. J. & Buz J. (2019) *LPS L*, Abs. #3802.

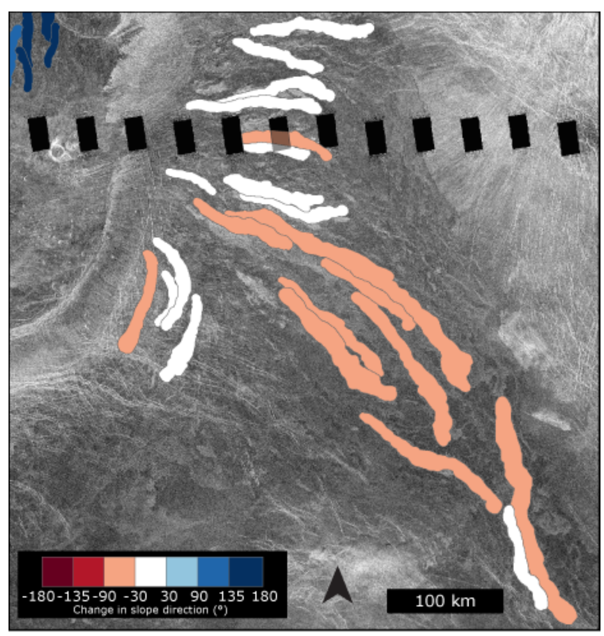

Figure 2. Mapped lava flows on the eastern flank of Atete Corona. Change in slope direction indicates counterclockwise rotation of the slope face.