MAGMA RESERVOIRS FEEDING GIANT RADIATING DIKE SWARMS: INSIGHTS FROM VENUS.
E. B. Grosfils[1] and R. E. Ernst[2]. [1]Geology Department, Pomona College, 609 North College Ave., Claremont, CA 91711 (egrosfils@pomona.edu), [2]Geological Survey of Canada, 601 Booth St., Ottawa, Ontario, Canada K1A0E8.

Introduction: Evidence of lateral dike propagation from shallow magma reservoirs is quite common on the terrestrial planets [e.g. 1,2], and examination of the giant radiating dike swarm population on Venus [e.g., 3-8] continues to provide new insight into the way these complex magmatic systems form and evolve. For example, it is becoming clear that many swarms are an amalgamation of multiple discrete phases of dike intrusion [7-10]. This is not surprising in and of itself, as on Earth there is clear evidence that formation of both magma reservoirs and individual giant radiating dikes often involves periodic magma injection [e.g., 11,12]. Similarly, giant radiating swarms on Earth can contain temporally discrete subswarms defined on the basis of geometry, crosscutting relationships, and geochemical or paleomagnetic signatures (see [1] and refs therein). The Venus data are important, however, because erosion, sedimentation, plate tectonic disruption, etc. on Earth have destroyed most giant radiating dike swarm's source regions, and thus we remain uncertain about the geometry and temporal evolution of the magma sources from which the dikes are fed. Are the reservoirs which feed the dikes large or small, and what are the implications for how the dikes themselves form? Does each subswarm originate from a single, periodically reactivated reservoir, or do subswarms emerge from multiple discrete geographic foci? If the latter, are these discrete foci located at the margins of a single large magma body, or do multiple smaller reservoirs define the character of the magmatic center as a whole? Similarly, does the locus of magmatic activity change with time, or are all the foci active simultaneously? Careful study of giant radiating dike swarms on Venus is yielding the data necessary to address these questions and constrain future modeling efforts. Here, using giant radiating dike swarms from the Nemesis Tessera (V14) and Carson (V43) quadrangles as examples, we illustrate some of the dike swarm focal region diversity observed on Venus and briefly explore some key implications for the questions framed above.

Methods: Ongoing analysis of giant radiating dike swarm systems on Venus relies principally upon interpretation of FMAP (75 m/pixel) Magellan data. Georeferenced images sinusoidally projected and digitally mosaicked in ArcGIS serve as the mapping base for evaluating regional geological and stratigraphic relationships. In addition, lower resolution synthetic stereo data from the U.S.G.S. [13] provide topographic information to refine our interpretation of the geology.

Observations: *Nemesis Tessera quadrangle*. This dike swarm has two distinct subswarm foci [14]. The older radial subswarm, centered at 25°N, 206.7°E, fans across ~180 degrees of arc out to distances of at least 150 km; some dikes may exceed 1000 km in length if geometrically similar but spatially disconnected lineaments to the NE are distal components of this subswarm. There is no appreciable topographic signature at the subswarm's focus. The younger radial subswarm, centered at 26°N, 207.5°E (125 km NE of the older swarm), has shorter fractures fanning through ~360 degrees of arc across at least 125 km. It is centered upon a 25 km diameter dome, an unnamed volcano which also feeds an extensive system of lava flows. *Carson quadrangle*. The dike swarm at Tumas Corona, centered at 16.3°S, 352.1°E [9], fans across 270 degrees of arc. The lineaments originate at a 50 km diameter caldera, radiating from there at least 300 km across the surrounding plains. However, there are two distinct sets of lineaments originating from the same focal point. This can be seen most clearly to the south, where the older set of lineaments is covered by deposits from crater Avviyar while the younger set, with distinctly different fracture spacing and a subtly different tectonic alignment, cuts these same deposits. A second interesting characteristic is the existence of a three-stage geographic migration of the active magma center, inferred from superposition and crosscutting relationships. The oldest stage of activity, inferred from the remnants of a 30 km diameter caldera centered at 16.1°S, 353°E which has been partially flooded by surface volcanism, retains no signs of a radiating dike system if one ever existed. The next oldest stage is defined by the somewhat larger caldera and multiple episodes of dike emplacement described above. The youngest stage of activity is defined by a 50 km diameter topographic dome, centered at 16.8°S, 351.6°E, which has uplifted and structurally deformed the pre-existing dike lineaments. From the absence of structural deflections, it appears that dike injection during the second stage of activity ceased before updoming of the third stage commenced.

Discussion: The two dike swarms described here illustrate some of the source region magma reservoir complexities commonly observed. In Nemesis Tessera, the two subswarms each have a distinct geographic focus (125 km apart) and period of activity. Unlike what has been documented for novae on Venus [7,8] the older subswarm has longer continuous fractures and greater fracture-to-fracture spacing than the younger subswarm. In the Carson quadrangle swarm, three discrete stages of magma reservoir activity are inferred, each centered ~100 km from the one which preceded it, suggesting systematic migration in the locus of volcanic activity with time. The giant dike swarm associated with the second stage consists of two subswarms, each radiating away from the same focus, but the shift from older, densely spaced fractures to younger, widely spaced fractures mimics what is seen in novae.

For the Carson quadrangle swarm, the diameter of the caldera (~50 km) constrains the size of the underlying reservoir: roughly speaking, it should also be ~50 km across [15]. If dike volume is constrained purely by the volumetric expansion capacity of the reservoir, it should be <1% of the reservoir volume [16]. (An alternative, that dike volume is unrelated to reservoir volume ("buffered" case of [4]), establishes no relationship between dike and reservoir volume.) Assuming an oblate ellipsoidal reservoir [17], the dikes (assumed here to be blade-like in 3D and ellipsoidal in cross-section) would need to exceed ~15 m in width to ensure that the dike half-height is less than the reservoir's semi-minor axis (a condition which would cause the dike to intersect the surface and erupt). This value is consistent with field observations on Earth and model predictions for dike widths on Venus [1], and thus there is internal consistency to the argument that dikes in the Carson quadrangle swarm could have originated at a single large reservoir whose plan view dimensions are constrained by caldera geometry—though it is important to recognize that both reservoir and dike volume, while directly coupled, remain fundamentally unconstrained by available observations. The first subswarm of the radiating system formed in response to hundreds of injections (or closely-timed injection sets) into the reservoir, each creating a new dike. This interval was followed by a period of quiescence before a second series of periodic injections occurred to form the second subswarm. The duration of the quiescent period is unknown; it was sufficient for the regional stress field to alter yet insufficient for the reservoir to solidify. The differences in the characteristic fracture-to-fracture spacing may indicate that (a) the injections into the reservoir occurred more rapidly than those of the first subswarm (i.e., before the time required for the local compressive stress perturbation induced by an individual dike's emplacement to subside), and/or (b) that fewer total failure-inducing injections into the reservoir occurred, resulting in a lower overall dike density.

For the Nemesis Tessera swarm no caldera is observed, so it is difficult to constrain the magma reservoir geometry. As one end member, if the two subswarms occur at points of failure along the walls of a single large reservoir (diameter >125 km), dike widths would have to exceed 180 m to prevent the dike half heights from exceeding the reservoir's semi-minor axis. This width is much greater than is typical for giant radiating dikes observed on Earth, suggesting that the Nemesis Tessera magma reservoir is unlikely to be this large; an alternate model may involve the presence of a larger magma source at depth feeding multiple smaller reservoirs near the surface [18]. Like the Carson quadrangle example, the Nemesis Tessera swarm may thus be defined by multiple stages of activity originating at several shallow reservoirs, although it is unclear whether the regular distance between different successive stages of magmatic activity for the swarms in both quadrangles is coincidental or if this provides as yet unappreciated information about the physics governing termination of one stage of magmatic activity and initiation of the next. Unfortunately, the size of the reservoir feeding each Nemesis Tessera subswarm is poorly constrained; in fact, for the younger subswarm where lineaments originate very close to a central point (as is true for many novae), it is plausible to infer either a very small central reservoir and buffered lateral dike emplacement or perhaps even the absence of a reservoir at all [2,19]. As a rough estimate, however, if the dikes are of the same minimum width as those inferred for the Carson quadrangle (~15 m), then the diameter of the oblate ellipsoidal reservoirs generating the Nemesis Tessera dikes should be ~30-40 km for the two subswarms observed.

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Acknowledgements: This project is funded in part by *Planetary Geology & Geophysics* grant NAG5-10157.