VENUS DIAPIRS: THERMAL OR COMPOSITIONAL? V. L. Hansen, Department of Geological Sciences, Southern Methodist University, Dallas, TX 75275-0395, vhansen@mail.smu.edu.

Introduction: Venus is presumed to have a heat budget similar to Earth but it apparently cools by a different mechanism than plate tectonics. Venus hosts two distinct sizes of circular features: ~300-400 small (200-km median diameter) quasi-circular coronae that record magmatic and tectonic processes [1, 2], and ~20 large (~1600-2600-km diameter) quasi-circular crustal plateaus and volcanic rises. All of these features are diapiric in origin: coronae represent mantle diapirs, and plateaus and rises record the surface signature of deep mantle plumes on ancient thin and contemporary thick lithosphere, respectively [3]. Artemis, a unique ~2600-km diameter circular feature, defies classification as a corona or plateau/rise. Artemis' size resembles plateaus/rises, yet its topography resembles coronae. We reexamine the surface evolution of Artemis through geological mapping in order to understand its formation. We argue that Artemis (trough, interior and exterior) represents the surface signature of a deep mantle thermal plume. Interior coronae record either small-scale convection or compositional diapirs spawned from the hot thermal plume during a global transition from thin to thick lithosphere. Furthermore, we show that median-sized coronae result from compositional rather than thermal diapirs, and that the bimodal sizes of small coronae and large plateaus/rises reflects the mode of diapir buoyancy and the location of diapir formation. Large thermal plumes rise from a warm lower core-mantle boundary layer and form plateaus/rises or Artemis; these features transfer heat from the core. Broad mantle upwellings spawn small compositional melt(?) diapirs in the upper mantle; these diapirs rise to form coronae and transfer heat from the mantle. Coronae in different tectonic settings (chains, isolated, or with volcanic rises) may reflect different mechanisms of compositional diapir formation.

Methods: We mapped Artemis' surface in order to determine the spatial and temporal evolution of tectonism and volcanism across Artemis. We used correlated digital data sets including Magellan C1-, C2-, and locally F-scale SAR imagery, altimetry and synthetic stereo [4]. We followed previously outlined mapping principles and methods, feature identification, and structural methodologies [5-9].

Results: Our map is consistent with recent mapping [10] although our interpretations of the map differ leading to a plume model of Artemis formation following earlier proposals [11-13], but subsequently discounted [10]. Artemis comprises a large topographic welt that includes a paired circular ~1-km deep trough (Artemis Chasma) and ~1-km high outer rise [13] that we divide into three major elements: chasma, interior and exterior. We refer to locations as: N = 12:00, E = 3:00, etc. The chasma hosts trough parallel normal faults and folds. Normal faults dominate from 11:30-2:00 whereas folds dominate from 6:00-10:30. The trough is poorly defined from 10:30-11:30. From 2-6:00 the steep inner slope hosts normal faults and the gentle outer slope hosts folds. The interior includes 5 coronae that record rich histories of spatial and temporal overlapping tectonism and volcanism. Trough-radial extension fractures and outboard trough-concentric wrinkle ridges dominate the exterior tectonic fabric.

We propose that Artemis formed as a coherent entity, not as several unrelated events [e.g. 10]. The coronae, chasma, chasma folds and faults, radial fractures, and wrinkle ridges can all be interpreted within a coherent tectonic framework consistent with temporal and spatial relations gleaned from available data sets.

Artemis Evolution: Artemis' size, shape and geological features are consistent with formation above a deep mantle plume [14]. As a deep mantle plume rises the lithosphere is uplifted, and, if lithosphere strength is exceeded, radial fractures should form centered above the plume head. Laboratory experiments aimed at modeling plume-lithosphere interactions result in the formation of a circular trough similar to Artemis Chasma [12]; as a model plume head approaches a rigid horizontal boundary it collapses and spreads laterally; a layer of surrounding mantle is squeezed out from between the plume and the surface resulting in a gravitationally unstable trapped axisymmetric instability and formation of an axisymmetric trough. The squeeze layer can also lead to small-scale convective instabilities inside the axisymmetric trough. Finite element models of the interaction of large thermal plumes with a lithosphere also show development of an axisymmetric trough [15]. Although these workers apply their model to coronae, we believe that it provides a better analog for Artemis because their resulting trough to trough diameter can be >1200 km--much larger than typical coronae. Additionally, documented trough slope asymmetry (i.e., steep slope along the inner trough) and the distribution normal faults and folds within the chasma are consistent with the model trough asymmetry [15].

Thus a deep mantle plume model can accommodate Artemis' major elements. Rising and flatten of the plume head leads to early uplift, doming, radial fracturing. As the plume head collapses vertically and spreads laterally an axisymmetric trough forms. Within the trough, material is pulled downward resulting in formation of normal faults and folds. The plume continues to spread laterally outboard of the trough resulting in continued radial fracturing and formation of concentric wrinkle ridges. The interior is affected by small scale convection cells or diapirs resulting in corona with radial fractures, and/or concentric fractures or folds, and associated volcanism.

The size of Artemis indicates that it almost certainly results from a thermal diapir or plume (buoyancy driven by temperature difference) rather than a compositional diapir [14], but are coronae the result of thermal or compositional diapirs, or a combination of the two? Although workers generally accept that coronae represent the surface signature of mantle diapirs, most do not explicitly define the nature of the buoyancy, or they assume that buoyancy is thermal. Whereas all diapirs are driven by density differences with their surroundings, density differences can be a function of temperature or phase change, or both. The type of buoyancy, thermal expansion versus phase change, affects how diapirs interact with their surroundings [16]. If a diapir is driven by temperature difference alone (a "thermal" [16]), surrounding material is entrained into the diapir and rise velocity decreases with time. If buoyancy is compositionally driven the rate of rise can be greater, and there is no entrainment; a compositional diapir rises at a constant velocity assuming a constant surrounding composition.

Simple buoyancy calculations using Stokes flow formula [17] taken together with geologic and structural mapping, and geologic constraints, indicate that coronae likely result from compositional, not thermal, diapirs. Assuming Earth-like properties for Venus' upper mantle, coronae diapirs, if thermally driven, would have to form in the lithosphere in order for them to rise before they cooled. We know of no mechanism that could generate such thermals; thus corona-diapirs are likely driven by compositional buoyancy, and could form as Raleigh-Taylor melt instabilities within broad mantle upwellings [18, 19], or as earlier formed compositional mantle heterogeneity. The spacing of broadly synchronous coronae of Hectate Chasma indicates that these coronae diapirs formed at mantle depths of 150-200 km [20]. Given a potential temperature of Venus mantle of ~1750°K [21], and mantle solidus curves [22-24] it is reasonable to expect that partial melts could form at ~150-200 km depths with a slight increase in background temperature due to a broad mantle upwelling. The resulting melt could be significantly less buoyant than the mantle [25]. There may be several different mechanisms to form small compositional mantle diapirs, and different origins might be reflected in the tectonic setting of the resulting coronae. Chains of coronae may represent Raleigh-Taylor melt instabilities formed above broad mantle upwellings [18,19]. Coronae within Artemis or coronae-dominated volcanic rises [26] may represent compositional melt diapirs spawned at shallow mantle levels by hot deep mantle plumes, and isolated coronae could represent other forms of compositional diapirs, such as mantle compositional heterogeneity.

We propose that the bimodal sizes of large plateaus/rises and small coronae reflect the mode of diapir buoyancy, and that these modes reflect the locations of diapir formation, and different heat sources and modes of heat transfer. Deep mantle plumes form at a warm core-mantle boundary layer, rise through the mantle, and form plateaus (ancient thin lithosphere) or rises (present thick lithosphere); this transfers heat from the core. Broad mantle upwellings (which form in response to mantle downwellings that form along the lithosphere cold boundary layer) spawn melt diapirs at relatively shallow mantle levels; these diapirs rise to form coronae, and transport heat from the mantle. Deep mantle plumes could also spawn small compositional diapirs that rise to form clustered coronae; such diapirs could probably only form coronae if the lithosphere is relatively thin [27], and thus may record times of thin to transitional lithospheric thickness.

References: 1. Stofan ER et al. 1992, *JGR 97*, 13347; 2. Stofan ER et al. 1997, in *Venus II*, AZ Univ. Press, p.9931; 3. Phillips RJ & Hansen VL, 1998, *Sci. 279*, 1492; 4. Kirk RL et al. 1992, JGR 97, 16371; 5. Keep M & Hansen VL 1994, *JGR 96*, 20947; 6. Ghent RR & Hansen VL 1999, *Icarus 139*, 116; 7. DeShon HR et al. 2000, *JGR 105*, 6983; 8. Hansen VL et al. 2000, *JGR 105*, 4135; 9. Hansen VL 2000, *EPSL 176*, 527; 10. Brown CD & Grimm RE 1995, *Icarus 117*, 219; 11. Herrick RR & Phillips RJ 1990, *GRL 17*, 2129; 12. Griffiths RW & Campbell IH 1991, *JGR 96*, 18295; 13. Sandwell DT & Schubert G 1992, *JGR 97*, 16069; 14. Griffiths RW & Campbell IH 1990, *EPSL 99*, 66; 15. Smrekar SE & Stofan ER 1997, *Sci 277*, 1289; 16. Griffiths RW 1986, Phys. *Earth Planet Inter. 43*, 261; 17. Turcotte DL & Schubert G, 1982, Geodynamics, John Wiley, 450 pp; 18. Tackley PJ & Stevenson DJ 1993, in Flow and Creep in the Solar System, Kluwer Acad. Publ., p.307; 19. Phillips RJ & Hansen VL 1994, AREPS 22, 597; 20. Hamilton V & Stofan ER 1996, *Icarus 121*, 171; 21. Stevenson DJ et al. 1983, *Icarus 54*, 466; 22. McKenzie D & O'Nions RK 1991, *J. Petrol. 29*, 625; 23. Walter MJ 1995, *J. Petrol. 39*, 29; 24. Herzberg C & O'Hara MJ 1998, *Earth-Sci. Rev. 44*, 39; 25. Campbell IH & Hill RI 1988, *EPSL 90*, 11. 26. Smrekar SE & Stofan ER 1999, *Icarus 139*, 100; 27. Koch DM & Manga M 1996, *GRL 23*, 225.