CONSTRAINTS A-Z FOR THE SURFACE EVOLUTION OF VENUS, AND A PROPOSED HISTORY. V. L. Hansen[1], [1]Dept. of Geological Sciences, University of Minnesota Duluth, Duluth, MN 55812; vhansen@d.umn.edu.

Introduction: Hypotheses that a global-scale catastrophic resurfacing event played a major role in the evolution of Venus' surface are widely accepted, however, a growing body of data are inconsistent with such hypotheses. This view emerged from early Monte Carlo models constructed to address two observations about Venus' ~1000 impact craters: 1) mostly 'pristine' preservation, and 2) near random spatial distribution [1,2]. However, subsequent modeling by several groups clearly shows that a wide variation in surface histories can accommodate these crater observations, indicating that catastrophic resurfacing is not a unique solution. Perhaps more importantly, a growing body of independent studies indicate that crater characteristics, and local and regional geologic relations are difficult, if not impossible, to reconcile with catastrophic resurfacing. This contribution summarizes new constraints for surface evolution derived from geologic mapping and analysis from a wide range of approaches and studies. All resurfacing models must address the new constraints derived from new geologic analysis.

Definitions: Catastrophic resurfacing (CR)–rare, short-duration event(s) across huge spatial area(s) [near global] that end quickly; large time intervals between events; Equilibrium resurfacing (ER)–numerous, frequently occurring, randomly distributed resurfacing events across small spatial areas and short time intervals between events [3-6].

What can impact craters tell us?: Observations: (***A,B***) Venus has ~1000 nearly pristine craters that are distributed in a near random pattern across its surface; (*C*) early image analysis indicated that ~175 craters show signs of modification; (***D***) craters range in diameter from 1-270 km, with 30-km average [3,4,7,8]; (***E***) Craters density results in a single average model surface age (AMSA) for the planet [9], however, (***F***) because impact craters show progressive degradation, we can distinguish relative ages of craters [10,11]. These relative ages together with crater density define (***G***) 3 AMSA provinces [12,13], with the Young AMSA province corresponding to the Beta-Atla-Themis (BAT) and Lada regions–characterized by high concentrations of young volcanic flows [14,15]. (***H***) Destruction of craters by burial requires ≥1 km thick flows [16,17]. Analysis of digital elevation models indicates that (*I*) >>175 craters show modification by volcanic processes, and (***J***) many craters *do not* lie at the top of local stratigraphy [18]. (***K***) Relative age interpretations of craters and wrinkle ridges are non-unique thus proposed timing of wrinkle ridge formation using crater is suspect [19]. (***L***) Venus lacks craters >270 km, indicating either no large crater were able to form, or if formed, they were destroyed.

What can Ribbon-Tessera Terrain (RTT) tell us?: RTT forms a distinctive unique tectonic fabric of ribbons, folds and graben, that characterizes all crustal plateaus [20,21], and occurs as inliers proposed as remnants of collapsed crustal plateaus [22-27]. Although the formation of RTT is debated all mechanism consider that: 1) ribbon and fold formation overlapped in time, 2) graben formed relatively late and 3) local volcanism accompanied RTT formation [25,26,28-30]. Thermal modeling indicates that ribbon formation requires a very high geothermal gradient across the region of RTT fabric development [28,31]. RTT fabric characterizes crustal plateaus, and although plateau formation is debated, all hypothesis include the following conditions [20,21,24,26,28-30,32-34]. ***M***) RTT fabric formation resulted in the destruction of earlier formed local impact craters. ***N***) Individual plateaus formed spatially separate from one another. ***O***) Individual plateaus formed at different times (i.e., time-transgressively). ***P***) Plateaus formed when Venus had a thin global lithosphere.

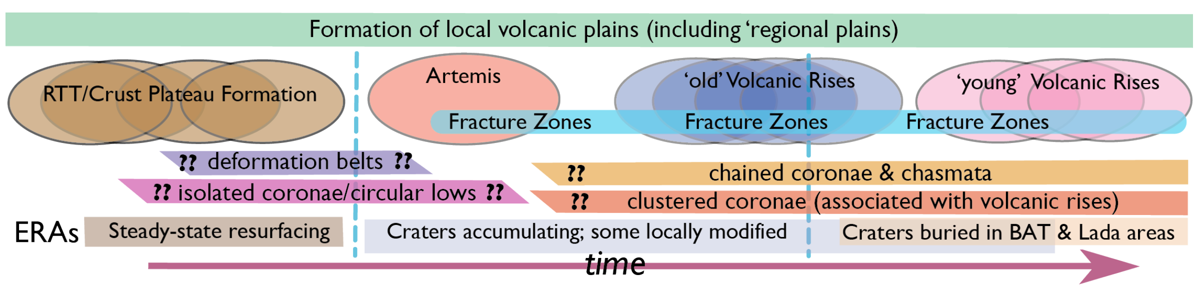
Global-scale RTT patterns provide additional conditions based on the following observations [35]. 1) RTT inliers occur within all volcanic rises, except Imdr and Themis. 2) RTT occurs within most lowland basins. 3) Within these basins, RTT occur independent of basin topography–that is, RTT can lie at the deepest levels of the basin or along the sides of a basin. 4) Groups of RTT inliers describe regional-scale linear to arcuate patterns. 5) Several of these patterns show no obvious correlation with long-wavelength topography–that is, RTT patterns track across both basins and rises. 6) Few, if any, large (>7×10^6 km^2) RTT-poor regions exist; an inverse statement is that RTT occurs in a widely distributed fashion across the surface of Venus. Thus, ***Q***) globally, low regions across Venus could not have been flooded/buried following RTT formation as proposed in the context of CR or global stratigraphy [5,36].

What can Artemis tell us? Artemis [37] is much larger than previously recognized, including a wide outer trough (>5000 km dia.), a radial dike swarm (>12000 km dia.), and a concentric wrinkle ridge suite (~14000 km dia.) [38]. The wrinkle ridge suite was previously described as 'circum-western Aphrodite' and attributed to topographic loading of western Aphrodite Terra [39,40], however wrinkle ridge patterns do not match model predictions, and the suite is better described as circum-Artemis. Artemis' evolution included formation of its interior and chasma, accompanied by lateral propagation of radial dikes; escape of dike magma to the surface formed local cover deposits that locally buried parts of fracture suite; cover deposits were cut, in turn, by wrinkle ridges. The outer trough formed late relative to radial fractures, cover deposits, and wrinkle ridges, possibly accompanying wrinkle ridge formation. ***R***) In order for these geologic relations to be preserved, greater-Artemis would have to form *after* proposed CR. However, Artemis likely represents the signature of a deep mantle superplume during an era marked by relatively thin lithosphere. Ishtar Terra, which is antipodal to Artemis, and previously proposed to have formed due to ponding of mantle melt residuum within a large regional downwelling [41], could have formed by downwelling driven by global-scale upwelling associated with the Artemis super-plume.

What can wrinkle ridges tell us? Wrinkle ridges also form concentric suites centered on several highland features including: Themis, Lada Terra, Gula Mons, Sappho Patera, Pavlova Corona, and Bell Regio [39]. Formation of these wrinkle ridges is inconsistent with formation caused by stresses induced in the lithosphere due to excursions in surface-T and the downward propagation of the resulting thermal wave superposed on the gravitational stresses associated with topography and lateral variations in lithospheric structure [42], given that the suites occur in areas at high elevation and/or with positive geoid values [39, fig.14a]. Furthermore, cross-cutting relations indicate that Artemis-concentric wrinkle ridges predate wrinkle ridges concentric to Bell [38]; these relations indicate that: ***S***) it is unlikely that wrinkle ridges formed at a single time in Venus' history, and ***T***) it is unlikely that wrinkle ridges formed as a result of postulated high surface-T related to global catastrophic volcanism [e.g., 43].

Constraints from volcanic deposits: Results of geologic mapping impose constraints based on volcanic deposits including: ***U***) evidence for contemporary volcanism base on emissivity data [44]; ***V***) geologic mapping of ~30% of the surface indicates that the majority of plains volcanic units can be tied to local identifiable sources , and ***W***) a wide range of volcanic units occur throughout local stratigraphic stacks, rather than occurring within a consist and unique order [17]. ***X***) Thin shield deposits occur across large spatial regions (covering ~22% of the surface), and formed time-transgressively, occurring at different stratigraphic locations in different areas, rather than a single restricted time period [17,45-48]–thus ***Y***) in order for these deposits to be preserved they would all have to post-date postulated CR. ***Z***) Several large regional map areas record 'non-directional' geologic histories [17,49] contrary to the sequence of events proposed within the context of proposed global stratigraphy that embraces CR [e.g., 36].

Viable resurface histories must account for constraints A-Z: Modeling indicates what is possible, not necessarily what happened; models do not impose constraints, rather they can serve as tests of hypotheses. It was in this vein that early Monte Carlo models ruled out ER models with specific incremental resurfacing rates, and indicated the viability of CR hypotheses [1,2]. However CR hypotheses violate, or are severely challenged by, constraints: G, J, Q, R, X, Z. Thus CR hypotheses are invalid. New Monte Carlo models that address crater distribution and preservation include models that consider changes in resurfacing rates (thus is not strictly ER) and also examine incremental resurfacing not previously modeled [50,51]. Model results indicate that crater observations can be met through surface histories with changes in resurfacing rates, and/or with viable resurfacing increments of 1-0.1% of Venus' surface, or ~5000-500 km^2. Each resurfacing scenario carries different geological requirements. A model evolutionary surface history consistent with **c**onstraints A-Z is presented.



References: [1] Bullock M.A. et al. (1993) GRL 20, 2147-50; [2] Strom R.G. et al. (1994) JGR 99, 10899-922; [3] Schaber G.G. et al. (1992) JGR 97, 13257-302; [4] Phillips R.J. et al. (1992) JGR 97, 15923-48; [5] Herrick R.R. (1994) Geol. 22, 703-6; [6] Basilevsky A.T. & J.W. Head (1996) GRL 23, 1497; [7] Herrick R.R. et al. (1997) Venus II, pp. 1015-46; [8] Hauck S.A. et al. (1998) JGR 103, 13635-42; [9] McKinnon W.B. et al. (1997) Venus II 969-1014; [10] Izenberg N.R. et al. (1994) GRL 21, 289-92; [11] Basilevsky A.T. & J.W. Head (2002) Geol. 30, 1015-8; [12] Phillips R.J. & N.R. Izenberg (1995) GRL 22, 1517-20; [13] Hansen V.L. & D.A. Young (2007) GSA-SP 255-73; [14] Head J.W. et al. (1992) JGR 97, 13153-98; [15] Crumpler L.S. et al. (1997) Venus II 697-756; [16] Herrick R.R. & V.L. Sharpton (2000) JGR 105, 20245-62; [17] Stofan E.R. et al. (2005) Icarus 173, 312-21; [18] Herrick R.R. & M. E. Rumpf (2011) JGR 116, 32pp; [19] Hansen V.L. (2000) EPSL 527-42; [20] Bindschadler, D. L. et al. (1992) JGR 97, 13495-532; [21] Hansen V.L. et al. (1999) Geol. 27, 1071-1074; [22] Ivanov M.A. & J.W. Head (1996) JGR 101, 14861-908; [23] Phillips R.J. & V.L. Hansen (1994) AREPS 22, 597-654; [24] Phillips R.J. & V.L. Hansen (1998) Sci. 279, 1492-97; [25] Hansen V.L. & J.J. Willis (1996) Icarus 123, 296-312; [26] Hansen V.L. & J.J. Willis (1998) Icarus 132, 321-343; [27] Ghent R.R. & I.M. Tibuleac (2002) GRL 29, 994-7; [28] Gilmore M.S. et al. (1998) JGR 103, 16813-40; [29] Romeo I. & D.L. Turcotte (2008) EPSL 276, 85-97; [30] Hansen V.L. (2006) JGR, 111; [31] Ruiz J. (2007) PSS, 55, 2063-70; [32] Bindschadler D.L. et al. (1992) JGR 97, 13563-77; [33] Bindschadler D.L. (1995) RGP 33, 459-67; [34] Hansen V.L. et al. (2000) JGR 105, 4135-4152; [35] Hansen V.L. & I. Lopez (2010) Geol., 38, 311-4; [36] Basilevsky A.T. & J.W. Head (1998) JGR 30, 8531-44; [37] *Bannister* R.A. & V.L. Hansen (2010) USGS SIM-3099; [38] Hansen, V.L. & A. Olive (2010) Geol., 38, 467-70; [39] Bilotti F. & J. Suppe (1999) Icarus 139, 137-57; [40] Sandwell D.T. et al. (1997) Icarus 129, 232-44; [41] Hansen V.L. & R.J. Phillips (1995) Geol. 23, 292-6; [42] Solomon S.C. et al. (1999) Sci. 87-90; [43 Bullock M.A. & G.H. Grinspoon (2001) Icarus 19-37; [44] Smrekar S.E. et al. (2010) Sci. 328, 605-8; [45] Addington E.A. (2001) Icarus 149, 16-36. [46] Brian A.W. et al. (2005) USGS SIM-2813; [47] Hansen V.L. (2005) GSAB 117, 808-22; [48] Grindrod P.M. et al. (2010) GRL 37; [49] Guest J.E. & E.R. Stofan (1999) Icarus 139, 55-66; [50] Bond T.M. & M.R. Warner (2006), LPSC 37, 1957.pdf; [51] Bjonnes E.E. et al. (2012) Icarus 217 451-61.