CRUSTAL PLATEAUS AS ANCIENT LARGE IMPACT FEATURES: A HYPOTHESIS. V. L. Hansen[1], [1]Department of Geological Sciences, University of Minnesota Duluth, Duluth, MN 55812 (vhansen@d.umn.edu).

Introduction: Venusian crustal plateau formation is one of the most hotly debated topics to emerge form NASA's Magellan Mission. Crustal plateaus', ~1500–2500 km diameter quasi-circular topographic plateaus that rise ~4 to 0.5 km above the surrounding terrain host distinctive deformation fabrics. Scientists generally agree that thickened crust supports crustal plateaus, as evidenced by small gravity anomalies, low gravity to topography ratios, shallow apparent depths of compensation, and consistent admittance spectra [1-4]. Debate centers on crust thickening mechanism. The downwelling hypothesis involves thickening by subsolidus flow and horizontal lithospheric accretion associated with cold mantle downwelling [2, 5-8], whereas the plume hypothesis accommodates thickening via magmatic under-plating and vertical accretion due to interaction of ancient thin lithosphere with a large thermal mantle plume [9-13].

Examination of surface geologic relations within four crustal plateau areas leads to new observations, and refined geologic surface histories presented in a companion abstract [14]. The resulting surface history interpreted from each plateau surface is difficult to address within the context of either the downwelling or plume hypothesis of plateau formation. In this contribution a third hypothesis for crustal plateau is put forth, plateau formation involving crystallization of a huge lava pond. In this contribution the emerge alternate hypothesis of crustal plateau formation is discussed and explored, including possible lava pond formation resulting from massive melting of the mantle as a result of bolide impact with ancient thin Venus lithosphere. Impact models have recently also been proposed for other large igneous provinces including Great Ontong Java Plateau on Earth [15,16] and the Tharis region of Mars [17].

Background: Neither the downwelling nor the plume hypothesis address all characteristics of crustal plateaus. Challenges to the downwelling model including, formation of a plateau shape, time required for crustal thickening, a relative hot geothermal gradient during deformation, and an increase the depth of the brittle-ductile transition with time [5, 9-12, 18-21]. The plume hypothesis can address plateau form, a hot geotherm, and an increasing depth to BDT, but contractional structures may prove challenging for this hypothesis. Although long-λ folds record very small strain and can be accommodated within the plume hypothesis [21], short-λ folds might prove challenging for the plume hypothesis. Thermal requirements suggested by ribbon formation models may also be way too high [22]. Indeed the results of the companion geologic mapping study present significant challenges to the plume hypothesis. Map relations indicate that folds formed throughout the deformation of crustal plateau surfaces.

Geologic surface history: Map relations presented elsewhere [14] indicate an extremely high geothermal gradient across individual crustal plateaus, consistent with suggestions of Gilmore et al. [22]. The dynamic picture that emerges includes a thin (~100 m or less) strong surface (~50-150 m thick; and presumably thinner if data allowed higher resolution of surface structures) that is able to deform in a plastic fashion. A low viscosity subsurface (below the strong layer) material, probably lava, leaks to the surface during progressive deformation, and the formation of progressively longer-λ folds reflecting the increased layer thickness, the result of both deformation and cooling. The structural development is similar to progressive cooling a lava flow and resulting development of longer-λ folds through time [23]. Map relations indicate that lava leaked to the surface throughout the deformation, filling local topographic lows, which were later uplifted and carried piggy-back fashion by progressively younger and longer-λ folds. The results of the mapping lead to the proposal of an alternative hypothesis for crustal plateau evolution, the deformation and progressive crystallization of a huge lava pond.

Lava Pond Hypothesis: The dynamic picture that emerges from geologic mapping seem to be that of a thin strong surface (~100 m thick) across large tracts of individual plateaus; the layer is able to deform in a plastic fashion, forming both small scale folds and orthogonal extensional structures across the fold crests. Below this strong deformable layer resides a material of much lower viscosity, likely liquid. The liquid locally leaks to the surface and floods local structural lows in the deforming strong surface layer. With progressive deformation the surface layer thickens, resulting in formation of progressively longer wavelength folds and accompanying extensional structures. The character of fold and extensional structures are similar to those that occur on the surface of pahoeho lava flows, although obviously mush larger in scale. Ratios of increasing longer fold wavelengths are consistent with basaltic composition lava [e,g, 23, 24]. As lava locally leaks to the surface it floods structural troughs including short wavelength fold troughs or extensional troughs. These flooded regions can be uplifted and preserved as later formed long wavelength folds carry previously formed, shorter wavelength structures piggy-back fashion, preserving a record at the surface that can be interpreted through mapping SAR imagery.

Considering the scale of Venusian crustal plateaus, and the likely hood of a bulk basaltic composition [25], the picture that emerges is one of a huge basaltic pond with a progressively thicker layer of basalt pond scum that forms and deforms at the pond surface. Presumably folding (and concurrent orthogonal extension) of the surface layer would be driven by convection in the basalt pond; basaltic pond lava could periodically leak to the surface locally, and flood local topographic lows marked by ribbon or fold troughs. Early flooded short-□ fold troughs could be preserved and carried piggy-back style on later-formed longer □ folds. The longest □ (~15 to 130 km), which likely reflect shortening <2% [21], might be related to late stage thermal or tectonic affects, rather than lava pond dynamics, although previously formed surface structures may well represent structural anisotropy that affects later deformation.

Impact formation of colossal lava ponds? How could such a large volume of lava form concurrently over areas the size of individual crustal plateaus? Crustal plateaus preserve no evidence of volcanic structures, and even the largest volcanoes in the solar system are dwarfed by comparison to Venus' crustal plateaus. The Greater Ontong Java Plateau preserves a region similar in size and perhaps magma volume required for the formation of an individual crustal plateau lava pond. Ingle and Coffin [15] proposed that the submarine greater Ontong Java Plateau, which rises 2-3 km above the surrounding ocean floor, may have formed as the result of massive melting of the mantle caused by the impact of an ~30 km diameter bolide with relatively young oceanic lithosphere. In a similar vein, Reese et al. [17] propose that the Tharis volcanic region of Mars may have formed as the result of a bolide impact. Although Ivanov and Melosh [26] argue against the formation of large volumes of melt resulting from bolide impact, Jones et al. [16] present arguments and modeling that support formation of the greater Ontong Java Plateau via bolide impact. A critical parameter to the formation of huge volumes of melt outlined by Jones et al. [16], thin hot lithosphere, might be even more easily accommodated on ancient Venus. In addition, such a huge body of lava, as proposed herein, might cool significantly more slowly on Venus than Earth [27] leading to interesting possibilities of the evolution of the basalt pond surface scum. As noted by Jones et al. [16], bolide impact might lead to the generation of huge melt volumes, but it could also spawn a moderately shallow mantle plume that could affect crustal plateau formation. Thus, it seems reasonable to at least entertain an impact formation model as third hypothesis for crustal plateau formation. At the very least, consideration of such a different hypothesis could lead to further refinement of many parameters of crustal plateau evolution, or Venus surface evolution [28,29].

It seems worthwhile to entertain the impact hypothesis, if only as a mind-stretching thought exercise. Impact formation of crustal plateaus could provide a mechanism for large scale, but 'local' resurfacing that is below the detectable spatial limit of crater statistics [30,31]. Pre-existing craters would either be completely destroyed, or preserved, depending on their proximity to the impact site. Monte Carlo modeling might provide useful tests using the location and sizes of crustal plateaus, and lowland tessera terrain as constraints. Perhaps Venus records a much richer and more extensive surface history then we currently appreciate.

Venus preserves several crustal plateaus, each with relatively unique topographic character as recently outlined by Nunes et al. [19]. In addition, many large arcuate tessera inliers that occur within the lowlands have been proposed by many as remnants of ancient crustal plateaus [32,33] and yet their topographic forms cannot result from plateau collapse as proposed [19]. Perhaps the wide topographic variability results not from collapse, but from differences related to the formation of individual features through impact and lava pond crystallization.

References: [1] S.E. Smrekar, & R.J., EPSL 107, 582-597 (1991). [2] DL Bindschadler et al. JGR, 97 13563-13577 (1992). [3] RE Grimm, Icarus 112, 89-103 (1994). [4] M Simons, SC Solomon & BH Hager, GJI, 131, 24-44 (1997). [5] DL Bindschadler & EM Parmentier, JGR 95, 21329-21344 (1990). [6] DL Bindschadler, G Schubert & WM Kaula, W. M.JGR 97, 13495-13532 (1992b). [7] DL Bindschadler, Rev. Geophys. 33, 459-467 (1995). [8] MS Gilmore & JW Head, Meteorit. Planet. Sci., 35, 667-687 (2000). [9] VL Hansen et al. Venus II (1997). [10] R.J. Phillips & V.L. Hansen, Science 279, 1492-1497 (1998). [11] V.L. Hansen & J.J. Willis, Icarus 132, 321-343 (1998). [12] V.L. Hansen, B.K. Banks, R.R. Ghent, Geology 27, 1071-1074 (1999). [13] V.L. Hansen et al., JGR 105, 4135-4152 (2000). [14] Hansen, LPC 2005. [15] S Ingle& MF Coffin, EPSL, 218, 123-134 (2003). [16] AP Jones et al., GSA Special Paper, in press 2005. [17] CC Reese et al., JGR, 109, E08009 (2004). [18] JG Kidder & RJ Phillips, JGR 101, 23181-23194 (1996). [19] D.C. Nunes et al., JGR 109 (2004). [20] CD Brown & RE Grimm, EPSL 147, 1-10 (1997). [21] R.R. Ghent & V.L. Hansen, Icarus 139, 116-136 (1999). [22] MS Gilmore et al. JGR 103, 16813-16840, 1998. [23] TKP Gregg, JH Fink & RW Griffiths JVGR 80, 281-292 (1998). [24] TKP Gregg, pers. Comm. (2005). [25] RE Grimm and Hess, Venus II, (1997). [26] BA Ivanov & HJ Melosh, Geology 31, 869-872 (2003). [27] D. Snyder, JGR 107, 5080-5088 (2002). [28] T.C. Chamberlin, J. Geol. 5, 837–848 (1897). [29] GK Gilbert, AJS 31, 284-299 (1886). [30] WB McKinnon et al., Venus II (1997). [31] B.A. Campbell, JGR 104, 21951-21955 (1999). [32] MA Ivanov & JW Head, J. W., JGR 101, 14861-14908 (1996). [33] RJ Phillips & VL Hansen, AREPS 22, 597-654 (1994).