UNUSUAL MID-SIZED VOLCANOES ON VENUS: CHANGES IN VOLCANIC PROCESSES.
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Introduction: The lithosphere of Venus and its evolution through time are incompletely understood. We have been studying mid-sized Venusian volcanoes (50-300 km diameter) that fall within regions covered by more than 1 radar image. These mid-sized Venusian volcanoes are understudied, in part, due to the inadequate resolution of the Magellan altimetry of ~10x20 km for determining key aspects of their shape. Using stereo-derived topography, we can obtain gridded topography and/or manual profiles with a horizontal resolution of ~1-2 km [1]. In these regions of stereo coverage, we have found three unusual volcanic constructs whose styles of volcanism appear to have changed drastically over time. We found six similarly unusual constructs with only cycle 1 coverage. An improved understanding of these constructs will provide better constraints on the evolution of Venusian volcanism.

Unusual Volcanic Constructs: Here we describe two classes of previously unrecognized volcanic constructs (locations in Table 1). The constructs in both groups show dramatic changes in eruptive behavior during the volcano's history.

High-Viscosity Lava Flows: We identified two constructs that appear to have high-viscosity lava flows emanating from the summit region: Amra Tholus and Laka Mons. Amra Tholus (53°N 98°E; Figure 1) is capped by a large caldera ~30 km in diameter. Generally radial lava flows can be traced back to the central caldera. Three radar-bright lava flows emanate from the edges of the caldera to the SSW, ENE, and N. Each of these broad lobes appears to be a single, contiguous lava flow, though smaller flows may be present at resolutions better than the Magellan imagery. The caldera interior has a hummocky texture surrounded by an annulus of radar-dim (and probably smooth) material. The caldera rim appears to be a series of concentric graben. High aspect ratio radial flows of apparent low-viscosity from Laka Mons are superposed by hummocky, broad flows primarily to the SW with a minor contribution to the NE. Laka Mons has no apparent caldera. Both constructs appear to have formed on regional plains material and are relatively isolated in that their formation appears unaffected by other volcanic constructs and they do not lie within one of the planet's major rift zones. Both show proximity to shield fields and ridged plains. Laka Mons formed near several coronae. Amra Tholus is ~115 km NE of a structure classified as a caldera, though we would argue this structure is more like a patera or corona. The boundaries of the flows of both volcanoes suggest they have higher silica content than typical Venusian lavas [3; 5]. The closest morphologic analogs to Amra Tholus and Laka Mons may be festoon flows, a type of flow with abundant arcuate ridges on its surface [3; 5]. However, festoon flows typically appear as stand-alone structures rather than as flows emanating from what otherwise appears to be a large volcano.

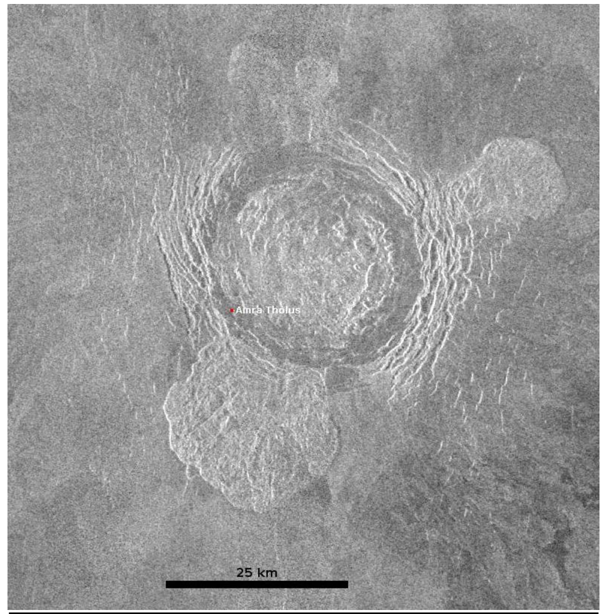

Figure 1. Cycle 1 (looking from left) Magellan SAR image of Amra Tholus, 53°N 98°E.

Lat/Lon	Name	Type
45°N 185°E	Nijole Mons	SSD-topped
8.5°N 255.5°E	Nipa Tholus	SSD-topped
2.5°N 314°E	-	SSD-topped
45°S 274°E	Abeona Mons	SSD-topped
9°S 305.5E	Muru Tholus	SSD-topped
21.5°S 238.5°E	**Gwen Mons**	**SSD-topped**
35°S 226°E	**-**	**SSD-topped**
53°N 98°E	**Amra Tholus**	**High-viscosity**
80°N 260°E	Laka Mons	High-viscosity

Table 1. Location, name, and type of unusual volcanic constructs. Bolded entries have left-right stereo coverage; none have left-left stereo coverage.

SSD-topped Volcanoes: These constructs appear to have started initially as shield volcanoes based on the faint (low radar backscatter) radial lava flows, but they are now topped by features that are morphologically similar to constructs elsewhere classified as Steep-Sided Domes (SSDs) [4], or colloquially "pancake domes." These constructs are unique in that the SSDs

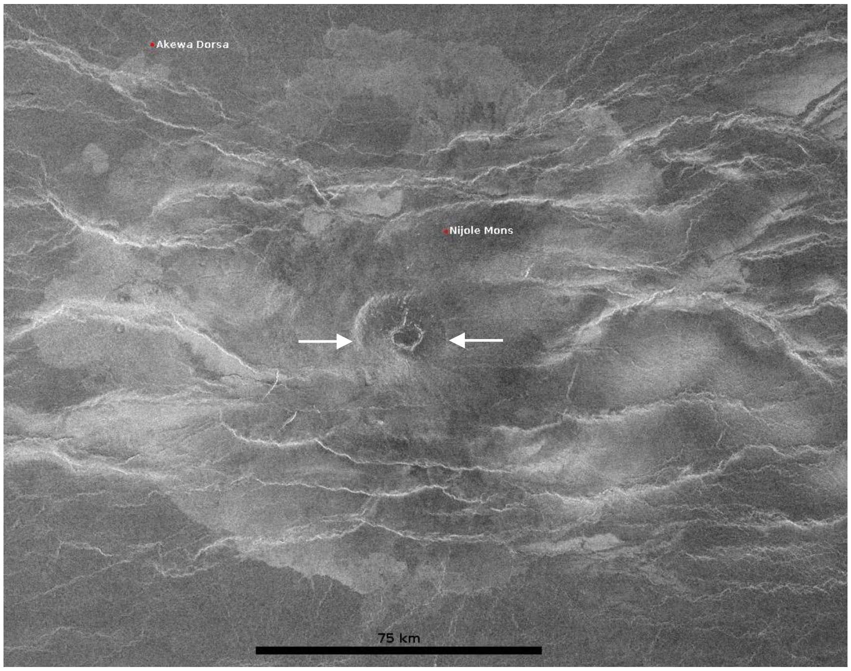

Figure 2. Cycle 1 (looking from left) Magellan SAR image of Nijole Mons, 45°N 185°E. The edges of the steep-sided dome can be discerned by a radar bright arcuate curve slightly left of center and the arcuate transition from radar dark to radar dim slightly right of center (white arrows).

are not stand-alone structures, but rather appear to have formed on top of an uplifted, broad volcano. We have found two volcanoes within stereo coverage with these characteristics: Gwen Mons (21.5°S 238.5°E) and an unnamed construct at 35°S 226°E. We found five other potentially similar constructs within areas that have only cycle 1 image coverage, making the extraction of useful topographic information difficult. One example of these is Nijole Mons (45°N 185°E; Figure 2), whose central SSD was initially mistaken for a caldera. Although we list these as SSD-topped volcanoes, several of these may be better described as fluted dome topped (e.g., Abeona Mons).

These SSD-topped constructs formed in regions atypical when compared to past research. SSD's are typically associated with shield plains [2]. Eighty-eight percent of 175 SSD's in [4] occur within ~150 km of other volcanic features. We found the SSD-topped constructs primarily in regional plains material and relatively isolated from other volcanic constructs.

Potential Causes/Implications:

High-Viscosity Lava Flows: We preliminarily conclude that Amra Tholus is the result of caldera collapse. We base this on the hummocky caldera center, the annulus of dark material, the graben surrounding the caldera, and the equanimity with which the areal coverage of the high backscatter lava flows are distributed. This conclusion suggests that these high backscatter lava flows have higher silica content than other Venusian lava flows and are the result of fractional crystallization in a large magma chamber, and/or remelting and incorporation of crustal material into the magma. The superposition and change in backscatter properties of flows from Laka Mons suggests a change from low-viscosity flows capable of flowing great distances to flows of much greater viscosity. The large areal extent and lack of a clear caldera suggests this construct is not the result of fractional crystallization, but more likely the incorporation of crustal material into the magma source and/or a change to a more silicic source. It is also possible the apparent change in viscosity is unrelated to any alteration of the chemical composition.

SSD-topped Volcanoes: Transitioning from producing radial lava flows to a SSD requires an increase in the effective viscosity. Early hypotheses to explain SSDs included a cooled skin, which might be allowed by a reduction in effusion rate, via continuous cracking and annealing of the cooled outer surface [4]. Alternatively, an increase in volatiles could occur, though this is difficult to explain following initially low viscosity flows. A pause in effusion could allow exsolved volatiles to concentrate in the uppermost magma column similarly to some terrestrial examples, though the high pressures inherent in the Venus environment make this seem unlikely. We conclude the most likely explanation for the increased apparent viscosity is an increase in crystallinity and/or a reduction in effusion rates that allowed formation of an annealing crust [4; 5].

Future work will 1) compare details of the high-viscosity lavas and SSD-topped volcanoes to the festoon flows and plains SSDs, respectively; 2) evaluate what aspects of the local geologic setting are important in the development of these constructs; and 3) consider and model likely changes in volcanic processes and compositions that resulted in these landforms.

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References: [1] Herrick et al. (2012) *EOS, 93*, 125-126. [2] Ivanov et al. (2015) *The Ency. Of Volc. (2nd Ed.)*, 729-746. [3] McColley & Head (2004) *LPSC XXXV, Abstract #1376*. [4] Stofan et al. (2000) *JGR, 105*, 26757-26771. [5] Wroblewski et al. (2019) *JGR: Planets, 124*, 2233-2245.