PYROCLASTIC DEPOSITS ON VENUS AS INDICATORS OF THE YOUNGEST VOLCANISM.

B. A. Campbell[1], G. A. Morgan[1], J. L. Whitten[1], L. M. Carter[2], L. S. Glaze[3], D. B. Campbell[4]; [1]Center for Earth and Planetary Studies, Smithsonian Institution, MRC 315, PO Box 37012, Washington, DC, 20013-7012, campbellb@si.edu, [2]University of Arizona, [3]Goddard Space Flight Center, [4]Cornell University.

Introduction: While most of the surface of Venus formed by effusive volcanic processes, deposits suggesting eruption styles that distribute airfall debris over large areas, or ground-hugging flows from plume collapse, are not common. Prior work notes radar-bright units with diffuse margins, generally consistent with a plume collapse emplacement model, in Eistla Regio, Dione Regio, and near Sappho Patera. We examine these deposits, and map additional occurrences, using Magellan data and Earth-based polarimetric radar maps from 1988, 2012, and 2015 observations.

Radar-Bright Deposits: Most Venus volcanic units are associated with typical basaltic morphologies such as lobate flow fronts, channel and levee structures, and pit-like or linear vents. With the exception of pancake domes and canali of enormous length, there are few features that have no obvious terrestrial parallel. One type of deposit not explained by simple flow emplacement exhibits strong radar echoes, diffuse margins, and a lack of internal lobes or channels. These were identified on volcanoes in Dione Regio [1], on corona margins in western Eistla Regio (Fig. 1) [2], and surrounding hybrid volcano-tectonic features near Sappho Patera [3]. All authors suggest some type of pyroclastic process to explain their distribution and radar scattering properties.

Earth-based radar mapping can achieve 1-2 km spatial resolution, with a dual-polarization capability that augments Magellan data. In particular, the Earth-based observations measure echoes in the same-sense circular (SC) mode, which is much more sensitive to small-scale surface roughness than to topographic slopes. The utility of these data were demonstrated in mapping of fine debris in the Venus highlands [4, 5], and we now have co-registered coverage of the side of Venus that faces Earth at inferior conjunction from 1988, 2012, and 2015.

VIRTIS data show 1.02-mm emissivity enhancements, relative to the typical Venus plains signature, interpreted as evidence for recent (though of indeterminate age) eruptions [6]. These sites include Hathor and Innini Montes, two of the Dione Regio volcanoes noted as having radar-bright, diffuse summit deposits [1], while Ushas Mons has neither enhanced 1.02-mm emissivity nor radar-bright summit material. This correlation suggests a potentially significant role of the radar-bright diffuse terrain in creating the infrared emissivity anomalies and perhaps being a signature of younger deposits.

Morphology and Distribution: The diffuse, radar-bright units have no marginal lobes or other features consistent with viscous flow. Their morphology, radar echo strength, polarization properties, and microwave emissivity are consistent with extensive mantling deposits comprised of small (few-cm) rocks. This coarse debris traveled downhill up to about 100 km on modest slopes, and blanketed pre-existing lava flows and tectonic features.

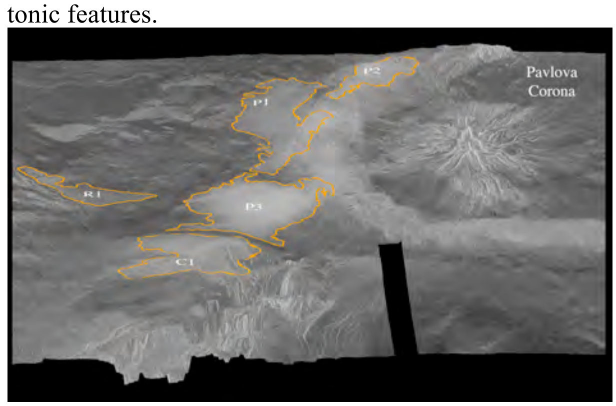

Fig. 1. *Perspective view of the western rim of Pavlova Corona, based on Magellan image and altimetry data. View from the south. Note downslope emplacement of radar-bright, diffuse units (outlined in orange) away from corona rims and/or densely ridged terrain.*

The sides of some lava flows just outside the diffuse deposits are evident in Magellan images, and thus are a few meters high; the coarse material must be similarly thick in these locales, but thins with downhill distance from the highest elevations. There is evidence for ongoing removal of the radar-bright deposits and exhumation of previously buried terrain (Fig. 2), so their initial extent may have been much greater.

Of great importance is whether this coarse material is stratigraphically "younger" than other deposits. The material forming the diffuse deposits covers all pre-existing features, and clearly grades in thickness and/or particle size downslope. Any erosion that has occurred would be due to in-situ breakdown since the wind can remove only fine debris. Wind streaks have covered portions of the diffuse deposits, suggesting that these features are at least old enough for this transport to occur.

Fig. 2. Full-resolution Magellan image of radar-bright, diffuse deposit northwest of Irnini Mons. Image width 188 km. Lobate flows disappear southwards beneath the bright mantling unit, and the dense streaks and residual patches suggest ongoing erosion of the mantle and exhumation of the flows.

New Feature in Dione Regio: Keddie and Head [1] present a detailed analysis of volcanic stratigraphy for Dione Regio. They note radar-bright, diffuse-margin material near the summits of Hathor and Innini Montes, and perhaps on Nepthys Mons. Only near the summit of Innini Mons does the radar-bright signature appear to arise from altitude dependent surface-atmosphere effects. These materials blanket lava flows and tectonic features, and suggest a pyroclastic or ignimbrite style of emplacement. Our combined Earth-based data from 1988, 2012, and 2015 offer a view of polarimetric scattering behaviors at a higher signal-to-noise ratio than that available to [1].

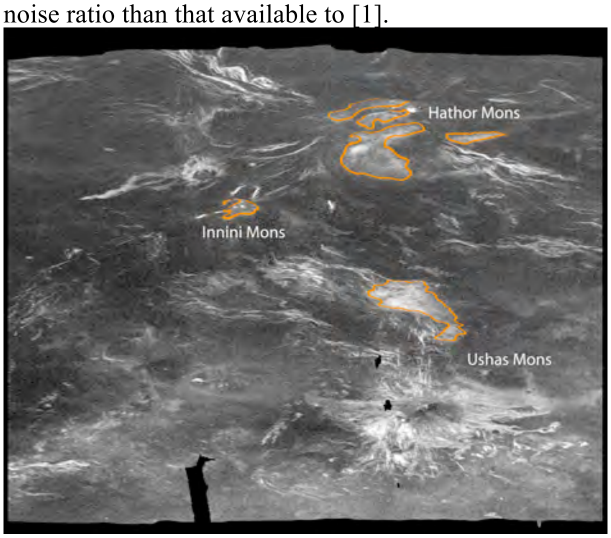

Fig. 3. Perspective view of Dione Regio based on the Earth-based SC image and Magellan altimetry data. View is from the north. Orange outlines denote occurences of radar-bright, diffuse terrain.

We map multiple areas of diffuse, radar-bright signatures on Hathor Mons and a large deposit along the densely fractured terrain just south of Ushas Mons. Ushas Mons itself appears to have no major instances of this type of deposit. The Earth-based SC image (Fig. 3) shows how strong the diffusely scattered echoes are, especially in the ridge-belt unit. Its location mirrors a similar correspondence with densely fractured terrain in Eistla Regio (Fig. 1). Radar-bright diffuse regions also occur near the summit of Hathor Mons (built up on intersecting ridge belts). This volcano has an inferred 1.02-mm emissivity enhancement from VIRTIS data, but there is no evidence of such emissivity changes for the radar-bright unit on nearby ridged terrain. If the ridge-belt deposit and the Hathor summit are of similar composition and grain size, this raises questions about the specific mechanism of the infrared emissivity changes.

Conclusions: In radar-bright, diffuse terrain, we find evidence for mantling of lava flows and tectonic features by coarse-grained debris up to several meters thick, which thins and perhaps is sorted to finer particle sizes downslope of the highest elevations. We also note evidence for erosion of this material, exhumation of flow features, and isolated outliers, implying larger initial extents. There is no clear evidence for embayment of the mantling deposits by later flows, so they are the stratigraphically youngest units except for wind streaks. The smaller occurrences exhibit some of these attributes, but often have less enhanced SC echoes. We speculate that these deposits are older, or were not as initially extensive or thick, such that subsequent erosion has left these minimal traces.

If the radar-bright units originate by collapse of low (few-km) eruption columns, with coarse, disrupted material entrained and fluidized by hot gases, then their extent and volume suggests very large erupted volatile (CO_2 or H_2O) amounts [7, 8]. One possibility is that these deposits reflect the early stage of new mantle plume activity, with volatile-rich, disrupted magma escaping through pre-existing fractured regions of the upper crust. Rapidly eroding under Venus surface conditions, or buried by subsequent volatile-poor eruptions, these markers of early plume activity have disappeared from older regions.

References: [1] Keddie, S.T., and J.W. Head, *JGR*, 100, 11,729-11,754, 1995; [2] Campbell, B.A., and D.A. Clark, USGS Atlas of Venus, *Sci. Inv. Map 2897,* 2006; [3] McGill, G.E., USGS Atlas of Venus, *Sci. Inv. Map I-2637*, 2000; [4] Campbell, B.A., et al., *Icarus*, doi:10.1016/j.icarus.2014.11.025, 2014; [5] Whitten, J.L., and B.A. Campbell, *Geology, 44,* 519-512, doi:10.1130/G37681.1, 2016; [6] Smrekar, S.E., et al., *Science, 328*, 605-608, 2010; [7] Thornhill, G.D., *JGR*, 98, 9107-9111, 1993; [8] Glaze, L.S, et al., *JGR*, 116, doi:10.1029/2010JE003577, 2011.