ERUPTED VOLUMES OF VENUS LOW SHIELD VOLCANO CLUSTERS. J. A. Richardson[1,2], D. M. Miller[3], and E. Gallant[3], [1]Planetary Geology, Geochemistry, and Geophysics Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771 (jacob.a.richardson@nasa.gov); [2]Department of Astronomy, University of Maryland, College Park, Maryland 20742; [3]School of Geosciences, University of South Florida, Tampa, Florida 33620.

Introduction: The volume of lava and other volcanic deposits that were emplaced in the venusian past remains an open question that limits our understanding of heat flow and geologic activity on Earth's nearest neighbor. The volumes of low shields themselves are unknown, and only their gross geomorphology has been described. Low shields are thought to have been constructed by lava and have low slopes of <2°, similar to low shields on Earth and Mars. Their diameters and planform shapes are better known from Magellan radar images (Figure 1).

Low shield individual volumes are inaccessible with Magellan-derived topography, since the diameter of each shield is within a factor of two of the topographic resolution of 4.6 km. Recent topography data has been processed using Magellan stereo images by Herrick *et al.* [1], with a nominal resolution of 600 m per pixel. This dataset remains coarsely resolved for individual low shields, but it is less than the radius of many identified low shields. Between the spatial resolution and the vertical uncertainty of this topography dataset, individual shields remain on the boundary of identifiability.

In this paper, typical topographic signatures of venusian low shields are identified with the stereo topography dataset by averaging elevation models centered on known low shield positions, cataloged by Miller [2]. This technique is validated using the East Snake River Plain (ESRP) Volcanic Field (Idaho, USA). With the resulting geomorphology of venusian low shields, volume, slope, and their implications for eruption processes at volcano clusters on Venus are analyzed.

Regional Setting: *Venus Study Area.* Overlap between the Herrick *et al.* stereo topography [1] and the Miller volcano catalog [2] exists in one region on Venus, roughly bounding 0-40° N, 120-140° E. This region straddles the Greenaway and Vellamo Quadrangles where small shields make up a primary geologic terrain [3], are distributed at elevations from -3 – 1 km above mean planetary radius, and are geographically intermingled with Coronae, which are larger magmatic or volcanic edifices [4].

Miller [2] cataloged volcanic landforms in two shield plains and two shield fields in this region using Magellan radar images. Together, the two shield plains plains have 6,379 low shields and are broadly distributed over an area of 2,000,000 km² [5]. The two shield fields are located in the Vellamo Quadrangle. The first field has 135 volcanoes and is located within the central depression of the 300 km-wide Boann Corona (27° N, 136.5° E). The second field is adjacent to the eastern boundary of Boann Corona (Figure 1) and has 169 volcanoes emplaced over about 9,000 km² [5].

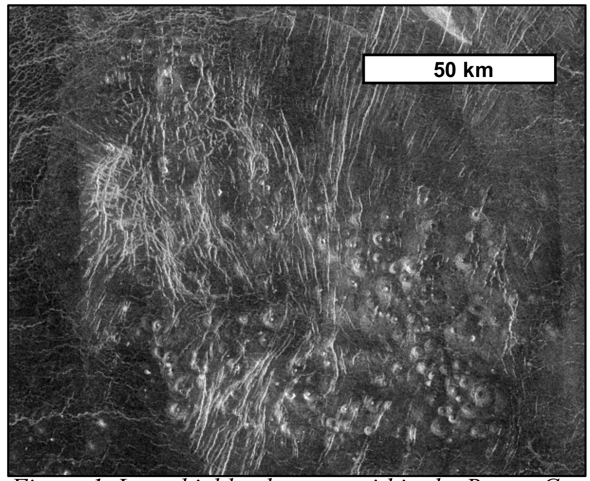

Figure 1. Low shield volcanoes within the Boann Corona, Venus. These 169 edifices form a shield field. Image: Magellan C1-MIDR 30N135.

Terrestrial Study Area. We compare these venusian volcano clusters to the ESRP, a distributed volcanic field of mostly low shields [6], like those on Venus. The ESRP is also analogous to venusian volcano clusters due to its intracontinental geologic setting [7,8]. Our ESRP catalog includes 509 currently exposed volcanic vents [6].

Methodology: To model the average morphology of volcanoes in a single volcano cluster, we combine and average "windows" of topographic data. Each window is selected from a digital elevation model (DEM), is centered on a cataloged volcanic edifice, and has a defined width of roughly twice the expected maximum volcano diameter in the cluster. Planar slopes within the topographic windows are detrended and the elevations of central grid cells are subtracted from the windows to define the expected edifice peak as 0 m. This processing creates windows of relative elevation. As existing topographic data within the Venus study area has areas of no data, due to the limited coverage of Magellan Cycle 3 radar images, we only include topographic windows around cataloged volcanoes where more than 50% of the grid cells have topographic values.

Topographic windows are stacked by addition and the resulting summed model is divided by the number of windows, producing an average model of volcano morphology.

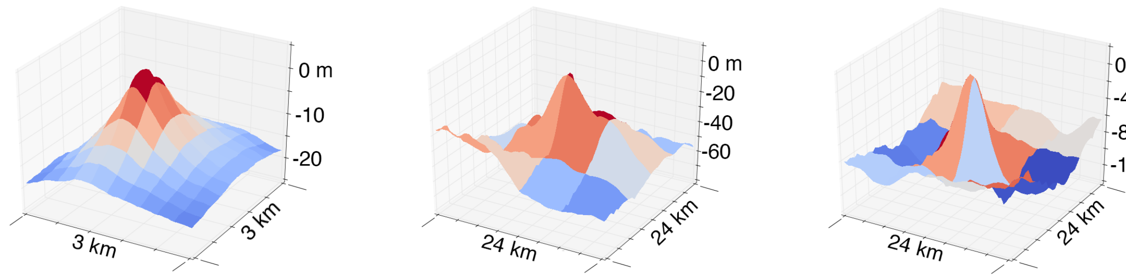

Figure 2. 3D views of averaged topographic windows centered on cataloged volcanic vents in (left) ESRP, (center) two Venus shield fields, and (right) two Venus shield plains. Elevation is labeled relative to peak height.

For Venus volcano clusters, we use Swaths 5 and 6 from Herrick *et al*. [1] with a nominal resolution of 600 m per pixel. For Earth volcano clusters, we use 1-arc second Shuttle Radar Topography Mission (SRTM) data, with a nominal 30 m per pixel resolution.

Results: We perform the above methodology on low shields within three shield volcano cluster types: Venus shield plains, Venus shield fields, and the ESRP (Figure 2). The average modeled Venus shield plain edifice is roughly 10 m in height and has a radius of about 6 km. The average modeled Venus shield field edifice is larger in height and radius, with an average height of 50 m and a radius of 9 km. ESRP shields are narrower than both Venus volcanoes, with an average height of 15 m and a radius of 1.5 km.

Given these dimensions, low shields on Venus shield plains have an average volume of 0.4 km^3, Venus shield field edifices are over 4 km^3 on average, and ESRP shields are just 0.04 km^3 on average. Average slopes from these models are 0.09° for shield plain volcanoes, 0.3° for shield field volcanoes, and 0.6° for ESRP volcanoes.

Discussion and Conclusion: The total erupted volume of volcanic shield plains and shield fields can be estimated with the modeled average shield volcano volumes. Given the number of cataloged shields in each cluster, the two volcanic plains have erupted 1100-1300 km^3 of igneous material each, the two volcanic shield fields have erupted 600-700 km^3, and the 509 ESRP vents have erupted just 17 km^3. These estimates rely on the assumptions that all volcanoes that form each cluster are cataloged and not buried and that all erupted volume from each cataloged vent was emplaced as a low shield instead of long lava flows or ash deposits and likely underestimate total erupted volume of each cluster.

Erupted volume per unit area is a valuable metric describing the productivity of distributed volcanism. Given the aerial extents of the shield clusters [5] and the total volume erupted as estimated here, we find that shield plains erupted about 0.001 km^3 over every km^2 in each plain, shield fields erupted 0.06 km^3/km^2, and the ESRP erupted 0.0008 km^3/km^2 from vents currently observable at the surface. Shield fields appear to have the highest volume erupted per unit area, while shield plains and the ESRP appear to have similar erupted volumes per unit area.

From these initial estimates, the total volumes of clusters of volcanoes on Venus formed from distributed volcanism are orders of magnitude smaller than Large Igneous Provinces (LIPs) on Earth (>10^6 km^3 of erupted material [8]) However, individual volcanoes within Venus shield fields are more massive than most volcanoes produced by distributed volcanism on Earth and might be more similar to typical low shields in martian shield fields [9] or the largest of lava flows at the ESRP, including the Wapi lava field [7]. The difference between morphologies of low shields in Venus shield fields and shield plains is currently unknown but might reflect differences in the magma source, style of production, ascent, or temporary storage in the venusian crust.

While our methodology does result in "shield"-shaped average volcanoes for each cluster (Figure 2), it is important to note that there exists some uncertainty in these models given resolution limitations in Venus surface data, which might enlarge the aerial extents of Venus average volcano models if cataloged volcano locations are spatially uncertain on the order of 10s-100s m. The spatial resolution of Venus stereo topography also adds to the morphometric uncertainty of the average volcano sizes and we have not attempted to measure lava flows extending from low shields, which likely have significant volumes of their own, with this data. Future topographic and image datasets with higher spatial resolution would significantly enhance our ability to quantify the erupted volumes of the volcanic provinces that have dramatically shaped the venusian surface.

References: [1] Herrick, R. R., *et al.* (2012). EOS, **93**(12), 125-126; [2] Miller, D. M. (2012) *SUNY Buffalo*, Masters Thesis; [3] Lang, N. P. & Hansen, V. L. (2010) *USGS Sci. Inv.*, Map 3089; [4] Stofan, E. R. *et al.* (1992) *JGR: Planets,* **97**(E8), 13347-13378; [5] Richardson, J. A. (2016) *USF*, Doctoral Diss.; [6] Gallant, E. *et al.* (2018) *Geology*, **46**(10), 895-898; [7] Greeley, R. & King, J. S. (1977) Volcanism of the ESRP, ID; [8] Bryan, S. E. & Ernst, R. E. (2008) *Earth-Sci Rev.*, **86**(1-4), 175-202; [9] Richardson, J. A. *et al.* (2017) *EPSL*, **458**, 170-178.