TRENDS IN DISTRIBUTED VOLCANISM ACROSS THARSIS PROVINCE, MARS. J. A. Richardson[1,2], J. E. Bleacher[1], Connor, C. B[3]., and Glaze, L. S[1], [1]Planetary Geology, Geophysics and Geochemistry Lab, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA (jacob.a.richardson@nasa.gov), [2]Universities Space Research Association, Columbia, MD 21046, [3]School of Geosciences, University of South Florida, Tampa FL, 33620.

Introduction: Small volcanic vents less than 10 km in length or diameter form in clusters on terrestrial planets as a product of distributed volcanism where low magma flux over a broad area enables volcanic activity while inhibiting the creation of a long-lived central edifice [1]. The juxtaposition of central volcanoes and distributed-style vents at the Tharsis Volcanic Province suggests that Tharsis has been built by a number of magmatic production events of varying duration and magnitude. We characterize the variety of distributed volcanism in the region and test to what extent distributed and central-vent volcanism are related and to what extent they are independent processes.

Small volcanic vents are ubiquitous in the Tharsis Province of Mars, between 21S – 40N, 76W – 139W (Fig. 1). Vents appear on the surface of Tharsis at virtually all elevations, from 2.4 km below mean datum in the moat of Olympus to nearly 17 km above mean datum on the summit of Arsia Mons [2].

Mapping: We consider the entire Tharsis rise our study area, roughly centering on Ascreaus Mons, with a radius of over 2,000 km, and an area of 13.6 million km^2, one-quarter of the Martian surface. We define the morphology of a small volcanic vent to be a topographic depression at the apex of a larger topographic feature, such as a low shield volcano or a cinder cone. A vent is tens of meters to a few kilometers in length or diameter and its surrounding volcanic construct is generally one to tens of kilometers in diameter with slopes of 0.5-4° and a height of 10-1,000 m. Each identified vent is cataloged as a geographic point location that is situated at the center of the vent. Additionally, the endpoints of each vent are also cataloged to measure vent orientation. We interpret each of the small volcanic

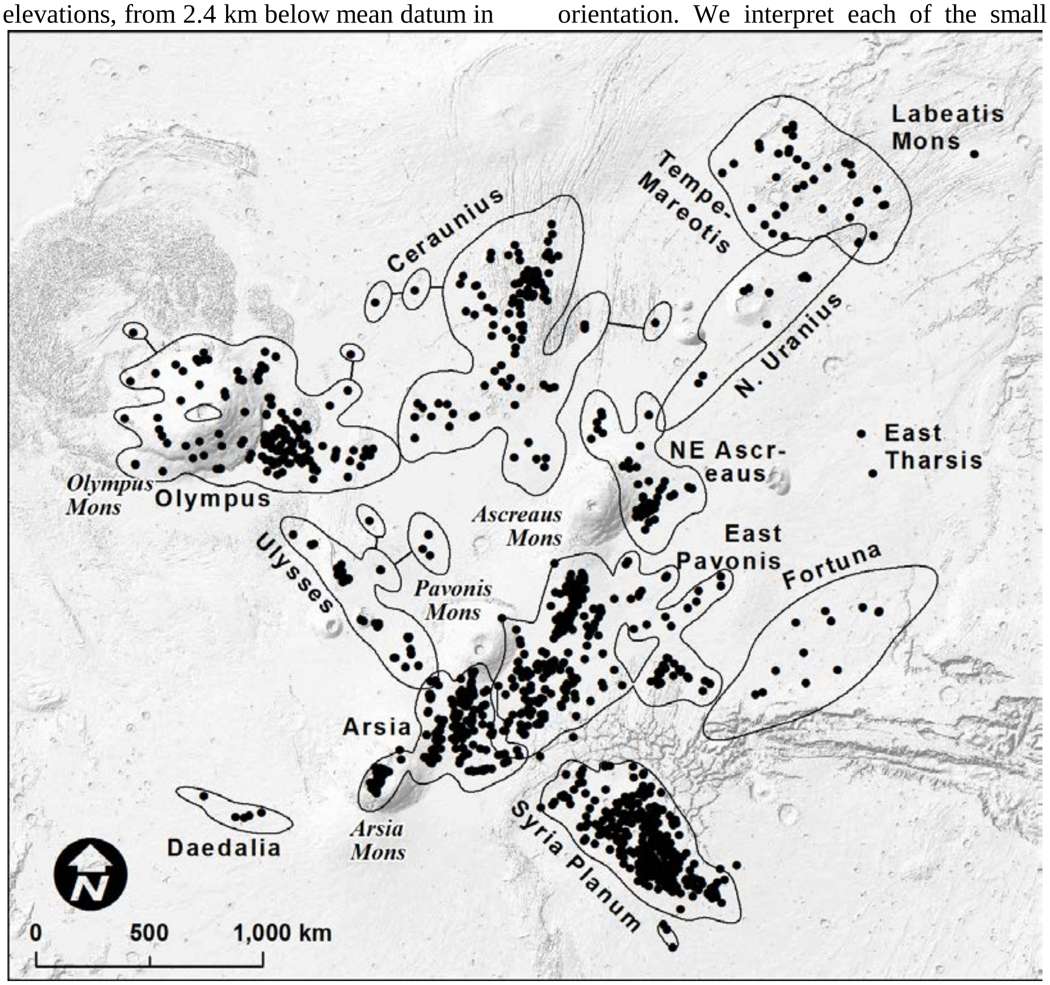

Fig. 1. The Tharsis Volcanic Province of Mars with the catalog of 1123 small volcanic vents plotted as circles. The boundaries of identified subregions with more than 3 vents are outlined in black.

vents that we catalog to be the surface location where magma erupted from the surface and produced an isolated volcanic feature.

Statistical Analysis: *Subregions.* A hierarchical clustering analysis is performed using vent locations in the data set to identify subregions of vents within Tharsis. Our approach is agglomerative, adding individual vents to nearby clusters depending on their distance to the centroid of that cluster, with a maximum radius of 600 km.

We identify 13 subregions within the catalog. We do not interpret each subregion to be a distinct geologic unit; instead, subregions are used to identify spatial trends in volcanism over the Tharsis region. Some subregions, including Syria Planum, Ceraunius, and Tempe-Mareotis are however regions previously identified as distinct volcano clusters [3-5].

Vent orientation. Orientation is measured using endpoints mapped for each elongate vent. We find that the majority of vents between Arsia Mons and Tempe Terra are aligned parallel to the Tharsis Montes and the graben set to their northeast. Many vents within 500 km of Olympus Mons and the Tharsis Montes are oriented radially to the closest large volcano. These two patterns indicate that multiple stress sources have influenced dike orientation in the subsurface of Tharsis.

Prominence. We calculate the height of each volcanic landform associated with a volcanic vent using the landform's topographic prominence, the vertical relief between a peak and its highest *col.* We find that vents with high prominence are generally found away from the central volcanoes. The highest vents are cones 0.1-1 km high in the Ulysses and East Pavonis subregions, while high low-shields >0.1 km high are found in Syria Planum and Tempe-Mareotis. On the flanks of the large volcanoes, vent prominence is generally 0-20 m.

Spatial Intensity. Kernel Density Estimation (KDE) is used to define the extents of each identified subregion, by modeling a spatial density function using vent locations. Subregion extent is defined by a contour that encloses 95% of all spatial density. Spatial intensity, the number of vents per unit area, is then calculated as the number of vents within that boundary contour and the area of the subregion (Fig. 2).

Age Modeling. Crater age modeling has been performed for select volcano clusters, which formed over 100s Ma, suggesting that melt sources beneath clusters are similarly long-lived. Average eruption repose intervals at Syria and within the Arsia caldera are estimated to be ~3 Ma [3,6]. Distributed volcanism has been a major process in Tharsis from at least the Early Hesperian [3,7] to the recent Amazonian [8].

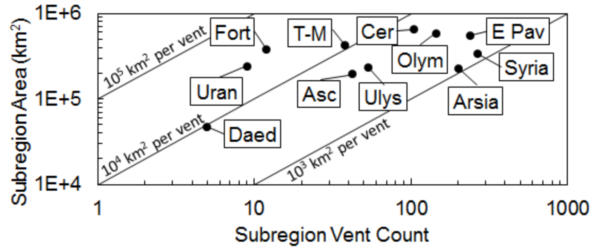

Fig 2. Subregion size with respect to number of vents. Vent spacing varies by over one order of magnitude across Tharsis.

Discussion: Each vent subregion has a signature shape and predominant vent orientations, which have implications into how the volcanoes in each subregion formed. Our interpretation is that three volcanic end-members have generated multiple distributed volcanic clusters on Tharsis.

1. Central volcano-dominated systems. Small vents in the proximity of large volcanoes will orient radially from the central edifice. Dike orientation might rotate in the ground as it encounters deviatoric stress from the edifice, which might be identifyiable in *en echelon* vent morphologies. Examples include Olympus and NE Ascreaus subregions.

2. Rift-dominated systems. Subregions elongate in the direction of graben sets also have vents co-oriented with grabens, indicating the regional volcanic style is heaviliy influenced by lateral extension. Examples include North Uranius and Ulysses subregions.

3. Plains-style volcanic systems. Subregions far from central edifices are less elongate and vent orientations are multimodal. These regions might have formed from magma production event(s) that are independent of central edifice construction or rifting in Tharsis. Syria Planum is interpreted to fit this style.

Subregions are influenced by these three processes to different extents. East Pavonis exhibits plains-style and central-volcano influenced volcanism, while Tempe-Mareotis exhibits a mix of plains-style and rift influenced volcanism. Trends of volcanism in these subregions show the complexity of long-lived distributed volcanism in the Tharsis Volcanic Province.

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