THE TARTARUS-COLLES CONE GROUP AND ITS IMPLICATIONS FOR EXPLOSIVE LAVA-WATER INTERACTIONS IN THE GRJOTA VALLES REGION OF MARS. C. W. Hamilton[1] and S. A. Fagents[1], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii, POST 504, 1680 East-West Road, Honolulu, HI 96822 USA, christopher@higp.hawaii.edu.

Introduction: Volcanic rootless cones (VRCs) are the products of explosive-lava water interactions and have been identified on Earth and Mars [1]. Terrestrial VRC groups cover areas of up to ~150 km^2 and generally include numerous conical landforms ranging from 1-35 m in height and 2-450 m in diameter [1]. VRCs are significant because they imply the presence of both active lava flows and an underlying volatile phase (*e.g.*, groundwater or ice) at the time of their formation [1]. We describe the Tartarus-Colles cone group on Mars and provide evidence to support the interpretation that these landforms are VRCs.

Background Information: Mariner 9 and the Viking Orbiter images resolved groups of kilometer-scale landforms that were interpreted as analogs to Icelandic VRCs [2, 3]. The Mars Global Surveyor re-imaged many of these groups at much higher spatial resolutions and revealed that the cones are located within lava flow fields and their morphologies and planar dimensions that are similar to the largest Icelandic VRCs. Alternative origins have been proposed for the Martian cone groups [4, 5]; however, both morphological [6, 7] and non-morphological evidence [8, 9] suggests that these features are VRCs rather than ice-cored mounds or secondary impact craters.

The Tartarus-Colles region is situated within the eastern part of the Elysium Rise in a region where Early Hesperian to Late Hesperian age lava flows inundate the topographic lows between the Late Noachian aged Nepenthes Mensae geological unit [10].

Methods: To investigate the origin of the Tartarus-Colles cone group, we combine geological mapping of satellite imagery with statistical geospatial analysis. The satellite images include: 6 HiRISE images (0.3 m/pixel), 7 HiRISE CTX images (6 m/pixel), 4 MOC-NA images (1.8-6 m/pixel), 8 THEMIS Visible images (18-19 m/pixel), and a THEMIS Infrared basemap (72 m/pixel). These data were imported into ArcGIS to create a coregistered mosaic upon which we based our geological map (Fig. 1A).

To determine if the spatial distribution of landforms within the Tartarus-Colles cone group exhibits a similarity to terrestrial VRCs, we compare an example from our study region with eight examples from the Laki lava flow using sample-size dependant nearest neighbor (NN) analysis [11] of crater centroids using Geological Image Analysis Software (GIAS; www.geoanalysis.org). The NN analysis utilizes two test statistics: *R* and *c*. *R* is the ratio of mean measured NN distance to the mean NN distance that would be expected given a Poisson random distribution of equivalent population density, whereas *c* is a test for statistical significance given the variance of the input. If the values of both *R* and *c* are within their respective sample-size dependant limits of significance then the input matches the Poisson random distribution model.

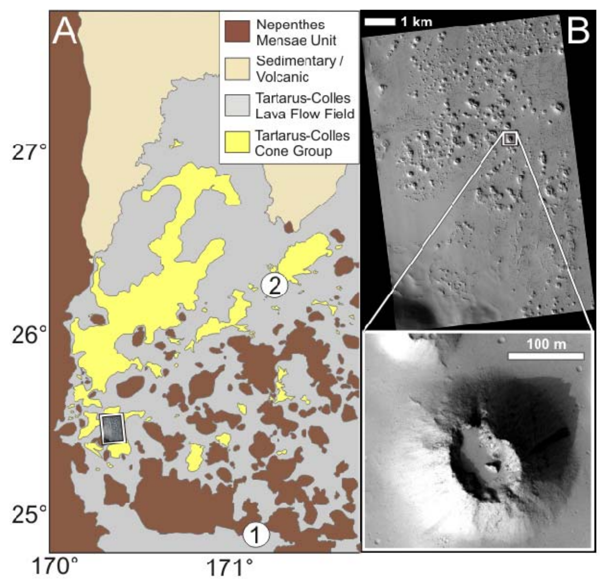

Figure 1. A: Geological map of the Tartarus-Colles Region. Lava in the study area is part of a compound flow field that was fed first from the southwest and then from the southeast—as evidenced by the lava channel at location "1". Conical landforms in the central part of the flow generally exhibit radial symmetry (*e.g.*, as demonstrated within the HiRISE inset shown in B), whereas cones in northern part of the flow tend to exhibit parallel elongations (*e.g.*, at location "2"). **B:** HiRISE image PSP_003900_2055 with inset showing mantled lava roughness, a radially symmetrical cone with a central crater, unconsolidated flank material, and a collapse block within the interior of the crater.

Results: Geological mapping reveals that the Tartarus-Colles lava flow field is composed of numerous flow units with overlapping lava breakouts. The flow field includes inflation features, kilometer-scale lava-rafts, and several lava channels. The flow field appears to be overlain to south by Late Amazonian age flood lava from Cerberus Planitia [12]. However, in the southern portion of the study area ("1" in Fig. 1A), there is a 6 km-long lava channel that flows through a breach in the Late Noachian aged Nepenthes Mensae geological unit. The channel widens to form a 1-7 km wide platy-ridged flow that is clearly part of the cone-hosting Tartarus-Colles lava flow field rather than an overlying unit. Thus, contrary to previous interpretations [10, 12], the Tartarus-Colles lava flow field is part of the Late Amazonian Cerberus Planitia flood lavas. Within the study area, 19% of the Tartarus-Colles lava flow field is covered in conical landforms that typically range from 50 to 150 m in diameter with a maximum range of 10-400 m. The cone groups range in area from <1 km^2 to 1323 km^2 (*i.e.*, nearly 10 times greater than the largest VRC Group on Earth) with an average of 49 km^2 and a total area of 1959 km^2. Individual cones typically exhibit the following characteristics: cone material rests upon the surface of the Tartarus-Colles lava flow, the apparent roughness of the lava flow decreases towards the cones, material on the outer cone flanks is unconsolidated and has locally destabilized to form slope streaks, material near the craters exhibits sufficient competency to form near-vertical faces and collapse blocks (*e.g.*, Fig. 1B). Within the northern cone groups there are numerous landforms with conical to crescent-shaped morphologies that exhibit parallel alignments of circular to elongate deposits. In some instances this material forms chains that extend up to 2 km in length (*e.g.*, "2" in Fig. 1A).

For the NN analysis, we compare a region in the Tartarus-Colles cone group to VRCs in the Laki lava flow. The Martian example includes 207 cones with a population density of 31.8 cones / km^2 and a mean NN distance of 108 m [11]. This yields R and c values of 1.22 and 6.14, respectively. Given sample-size dependent thresholds of significance, the Martian example exhibits a repelled distribution (*i.e.*, the cones are spaced further apart than expected given a Poisson random model). When compared to the Laki examples, the Martian test case is most similar to Hnúta Subdomain 1.1 ($R = 1.23$; $c = 4.30$) and Hrossatungur Subdomain 6.1 ($R = 1.21$; $c = 4.45$). This confirms that the cones of the Tartarus-Colles Group exhibit both morphological and non-morphological similarities to terrestrial VRCs and that the processes generating repelled eruption sites in our study area may be similar to those within some regions of the Laki lava flow.

Interpretations: On the basis of morphological and geospatial evidence, we interpret that the Tartarus-Colles cone group is composed of VRCs. The rootless tephra deposits include widespread pyroclastic deposits that obscure the roughness of the surrounding lava flows and grade into vent-proximal conical landforms each with a central crater. Induration of tephra deposits along the rootless crater rims is attributed to welding of spatter deposits. Spatter-rich deposits suggest that the rootless eruptions were water-limited. This is consistent with the self-organization of rootless eruption sites into repelled spatial distributions, which would maximize the utilization of limited water resources.

The cones of Tartarus-Colles Group include two dominant types: (1) radially symmetric cones composed of tephra that was deposited onto the surface of a stationary lava crust (*e.g.*, Fig. 1B) and (2) chains of tephra cones that were erupted from a fixed rootless eruption site and emplaced onto the moving surface of a broad flow [13]. The former rootless cone type suggests that the underlying flow is a thermally-insulated endogenous lava supply system that is analogous to terrestrial pahoehoe, whereas the latter rootless cone type implies a non-stationary lava surface similar to that of rubbly pahoehoe and platy-ridged flows [12]. In the Tartarus-Colles lava flow field the rubbly / platy-ridged flows are located to the north of the high relief Nepenthes Mensae unit where the lava exits a network of valleys and emerges onto a broad smooth plain. This region is analogous to where the Laki lava flow exited the Skafta River Gorge in 1783 on June 18, 21, and 29 to produce rubbly / platy-ridged lava flows [14].

Conclusions: The Tartarus-Colles lava flow field is a part of the Cerberus Planitia flood lavas and thus much younger than previously estimated. The landforms within the Tartarus-Colles cone group are of contemporary age with the Tartarus-Colles lava flow field and exhibit morphological and geospatial similarities to VRCs in the Laki lava flow. We therefore conclude that the Tartarus-Colles cone group formed by explosive lava-water interactions, which may have involved water-bearing sediments and lava flows generated by volcano-ice interactions in the Grjota Valles region.

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