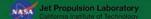
## TO DALLAS



Abstract: Cratered cones, interpreted to be volcanic rootless cones (VRCs), occur atop the Athabasca Valles Flood Lava (AVFL) in southwestern Elysium Planitia. The cratered cones concentrate within southern Cerberus Palus, a lava-inundated basin, and the Aeolis Trough, which is a valley formed by the crosional retreat of the Medusae Fossae Formation (MFF). These regions represent fundamentally different paleo-environments and we compare and contras the cratered cones within these two locations to determine if differences in the underlying substrate, including lithology, water abundance, and overlying lava thickness may have contributed to different eruption styles and cratered cone morphologies. We conclude that rootless eruptions in Cerberus Palus may have been triggered by unloading of the sub-strate during a "fill and spill" event, as ponded lava within Cerberus Palus drained and flowed into the Aeolis Trough. Cratered cones near the spillway in southern Cerberus Palus occur in association with fragmented lava plates and ex hibit elongate to radially symmetric shapes, implying that the explosive lava-water interactions initiated during the drainage event, but continued after the lava flow surface came to rest. In contrast, cratered cones in the Aeolis Trough tend to be aligned with yardang orientations within the MFF, implying that they formed above the lava-buried ridge crests, where lava flow was thinnest. The region also includes highly irregular low-relief ring-shaped structures that are inferred to be the products of isolated phreatic explosions, rather than the longer-lived cycles of phreatomagmatic activity that formed the larger cones within Cerberus Palus.

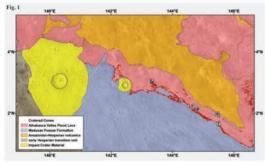


Figure 1. Regional map of the Aeolis Trough with the locations of images in Fig. 2 outlined in black boxes The red dots represent individual VRC candidates. The geologic units displayed are modified from Tanaka et al. (2014). Basemap is THEMIS Night IR.

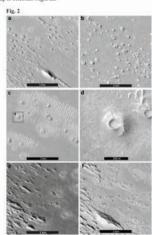


Figure 2. Gallery of landforms in the Acolis Trough and their morphological diversity. North is up in all images. a) Elliptical cratered cones in the Aeolis Trough. Flood lava has draped the smaller, meso-yardangs, leaving a combination of lava covered mounds and cratered cones. The orientation of the cones is nearly uniform and parallel to yardang orientation. HiRISE image PSP\_002622\_1820. b) Cratered cones towards the center of the trough. Shapes vary from somewhat elliptical, to radially symmetric, to amoeboid. Summit craters range from deep and hollow to nearly flat and flush with the crater rim. HiRISE image ESP 036497 1820. c) Cratered cones nearing the center of the trough. Shapes are primarily radially symmetric. Cones are commonly surrounded by light colored surface ma dotted with small craters. Transverse acolian ridges are also present near the cones, possibly comprised of eroded and redistributed MFF material. HiRISE image ESP 036220\_1820. d) Close up of a radially symmetric cratered cone in Fig. c. Outer cone walls appear steep and smooth. Small cracks are also present along the flanks. HiRISE image ES-P 036220 1820. e) Cratered cones near remnant MFF material on the northern side of the Aeolis Trough. Shapes of these cones are primarily elliptical, especially those closest to the lava druped meso-yardangs. Light toned aprons and transverse acolian ridges are also present here. CTX image B10 013355 1825. f) Pitted terrain in the Acolis Trough. adjacent to high-standing, lava embayed MFF material. Cratered cones of varying shapes, both elliptical and more symmetric, lie nearby. HiRISE image ESP\_013355\_1815.

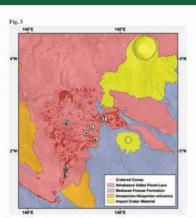


Figure 3. Regional map of southern Cerberus Palus with locations of images in Fig. 4 outlined in black boxes. The red dots represent individual VRC candidates The geologic units displayed are modified from Tanaka et al. (2014). Basemap is THEMIS Night IR.

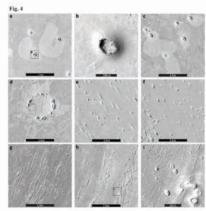


Figure 4. Gallery of landforms in southern Cerberus Palus and their morphological diversity. North is up in all images, a) Symmetrical cones in southern Cerberus Palus. Cones are enveloped by smooth, light toned, polygonal textured surfaces Surrounding the smooth material are rough and blocky surface material. The smooth terrain is lower than the rough terrain, indicated it was not inflated or extruded on top. Cones have steep, smooth walls, and meter sized boulders within their summit craters. HiRISE image ESP\_037222\_1820. b) Close up of a cratered cone in Fig. a. Note the smooth, steep outer crater walls and the boulders infilling the summit crater, c) Cratered cones nearing the center of southern Cerberus Palus. These cones are also generally radially symmetric in shape and surrounded by smooth, light toned surface material. HiRISE image ESP 012366 1825. d) Cratered cones in a circular grouping in the center of southern Cerberus Palus. Cones range in shape from elliptical, to radially symmetric, to amoeboid. Summit craters are generally wide and deep and there are often multiple, overlapping craters within single cone. HiRISE image ESP\_046308\_1825. e) Cratered cones in southern Cerberus Palus, adjacent to Zephyria Planum. Cones are generally elliptical in shape. Kipukas are visible where lava has embayed some of the mes leaving islands of high-standing material. HiRISE image ESP\_054615\_1820. f) Cratered cones on the eastern margin of southern Cerberus Palus, adjacent to remnant Zephyria Planum MFF material (present in bottom left of image). These cones are also elliptical in shape and neighbor lava draped mounds as well as lava embayed yardang kipukas. HiRISE image ESP\_026383\_1830. g) Cratered cones and pitted ridges in the southern spillway of Cerberus Palus. HiRISE image PSP\_008674\_1815. h) Cratered cones are pitted ridges in the southern spillway of Cerberus Palus. HiRISE image ESP\_037288\_1815. i) Close up of a cratered cones in Fig. h, partially surrounded by moats. The moats are evident in the two cratered

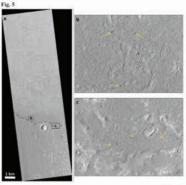


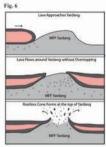
Figure 5. At the western margin of Cerbenis Palus, where thin flows of lava drape the Amazonian-Hesperian volcanies substrate there are small, thin-rimmed, circular constructs. There is no indication of ash ejecta or fragmented substrate material. The black line represents the contact between Amazonian-Hesperian volcanies and the Athabasca Valles Flood Lavas, and the arrows point to examples of these thin rimmed HiRISE image ES-P 037710\_1825.

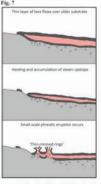
## Interpretations:

The locations of individual VRCs in southern Cerberus Palus was likely influenced by a combination of factors, such as the under lying topography, varying volatile availability, and lava crust ge-ometry. The lack of moats (except in the spillway) and the presence of the smooth, hummocky surfaces that surround Cerberus Palus cones indicate that they formed within the weaker interplate lava that was exposed following of the crust. Therefore, we interpret the symmetrical VRCs within the lava lake to have formed after drainage of the ponded lava, once molten lava from the inte rior was able to reach the surface after disruption and breakup of the brittle crust

The presence of cones on the peaks of buried yardangs is not unexpected and likely linked to the lower overhunden pressure of the thin of the overlying layer of lava [1,2]. However, also visible are some yardangs with rootless cones on top which are embayed around the sides but not overtopped by the lava, as well as the pitted terrain lying above the lava surface. This means that the steam created by the heat of the lava interacting with the subsurface volatiles had to travel up through the yar dang to explode. This transport may be possible due to the MFF's unusually low density and porous nature [3-5]. Thus, in the case of the yardang VRCs, we interpret these to have formed due to lateral transport and buoyant accumulation of steam towards the buried yardang highs, where the volatiles became pressurized and exploded through the yardang hull cap rock and overlying lava (as illustrated in Figure 6).

The thin rimmed rings found along the western flow margin of Cerberus Palus were probably formed in a manner analogous to 'bubble bursts' [6,7], in which passive volatile escape occurs through the thin lava near the flow margins (as illustrated in Figure 7). These eruptions were less energetic and did not result





## Conclusions

- . In southern Cerberus Palus, volcanic rootless cone formation was controlled by the 'fill and snill' style of lava emplacement [8]. Steam eruptions were triggered by draining of the ponded lava, which led to depressurization of supercritical fluids in the substrate, allowing them to vaporize and excavate overlying lava to construct cratered cones.
- · At the western margin of southern Cerberus Palus, 'thin rimmed rings' analogous to spatter rims formed due to steam escaping through the substrate, towards flow margins. Low energy bubble bursts through the thin lava created rings of competent spatter.
- Where the AVFL interacted with the MFF material surrounding southern Cerberus Palus, volcanic rootless concept referred to the concep
- . The pitted terrain in the Aeolis Trough was created as a by-product of some mechanism similar to hydrothermal venting, where steam generated in the lava heated substrate escaped explosively through high stands of less consolidated MFF material, constructing rimmed pits of fragmented material.

References [I] Jueger WL, Keszhelyi LP, McEwan AS, Dandus CM, Ressell PS, 2007. "Adubased Valles, Man: A Lawa-Dapped Clumord Systems" Science, vol. 377, 1709–1711. [2] Jueger WL, Keszhelyi LP, Skinner Jr. La, Milazus MP, McEwen AS, Tinus TN, Rosick MR, Galaszka EM, Howingson-Krase E, Kirk EL, HRISE Team. 2010. "Emploacement of the youngest flood laws on Man: A short, netwiden story," Science, vol. 205, 230–243. [3] Winters TR, Campbel B, Cainer L, Lesschee CJ, Tinus L, H., Campbell BA, Water EL, Tinus L, Campbell BA, Water EL, Tinus L,