
Introduction: Patches of disrupted terrain are found across southern Elysium Planitia. To better understand these features we examine examples associated with the Athabasca Valles Flood Lava (AVFL), the youngest and best-preserved flood lava flow on Mars [1,2]. Our working hypothesis is that these features indicate lava invasion of weak sediments.

Observations: This study focuses on locations in Cerberus Palus with clusters of tilted blocks forming irregularly faceted terrain (Fig. 1). At one location the blocks have a close jigsaw fit suggestive of a disrupted surface surrounding an impact crater. A second site appears more disrupted, with more widely-separated blocks and less trace of the pre-fracture terrain. The blocks have a resistant cap layer which shows that some blocks have tilted (Fig. 1a). The tilts of adjacent blocks are loosely consistent in the first case, but the more disrupted locality shows tilts in all directions, often with no correlation between adjacent blocks (Fig. 1b). Both sites are surrounded by AVFL, which filled Cerberus Palus with a depth of tens of meters before spilling out [2]. At the first site, the lava appears level up to the edge of the tilted-facet terrain, with no clear indication of a flow margin. The second, more disrupted site lies in a shallow (~20 m) depression, with faint fractures lining the crest of the rise. The bottom of the depression has identical lava textures, which fade into the region of disrupted blocks. The topography of some disrupted terrains indicate at least several meters of uplift (Fig. 1c) but others are ambiguous. Terrains with similar fracture patterns are found elsewhere in the Elysium Planitia region, commonly associated with the Medusae Fossae Formation (MFF) (Fig. 1d).

Timing: The timing of terrain disruption was likely penecontemporaneous with lava flow emplacement. Because there are no well-defined flow margins around the blocky terrain, it is unlikely that disruption preceded the lava unless talus completely obscures the contact. Clear margins are seen around many other kipukas within Cerberus Palus but the lava gradationally fades around the disrupted blocks. Such a relationship could be produced by material superposing the lava, but it is unlikely that the terrain could be so thoroughly disrupted without any effect on a solidified lava flow. Based on the locations within the AVFL, the most likely explanation is that the deformation was a consequence of lava emplacement.

Formation: The tilted-facet terrain requires a spatially inhomogeneous combination of uplift, translation, and removal of pre-lava material. The removal is very efficient wherever the cap layer is removed. The erosion almost certainly has an eolian component but we cannot rule out the possibility that loss of a volatile (presumably water ice) is also involved. This type of disruption is only seen in young terrains that share characteristics with the MFF.

The observed indications of uplift argue against formation by volume loss under an older high-standing surface. This also rules out the simplest explanation, that heat from the lava removed ground ice under the blocks and caused collapse. Additionally, the diffusion of heat laterally over kilometers in the shallow subsurface is minimal. Instead, softening by advection of some fluid is required. Lava, mud, and water (ultimately formed by the heat of the lava) are all plausible.

Lava is the simplest fluid to call upon, since vast quantities of it are directly adjacent to the blocks. Large (multi-km) intrusions by “invasive” lava have been documented on Earth in association with the Columbia River Basalt Group [3-5]. These are typically associated with fine-grained, wet sediments, which are deformable and allow intrusion via density inversion. MFF materials are likely fine-grained and low-density [6], and rootless cones on the AVFL testify to the former presence of water or ice [1-2]. Both uplift and formation of dikes have been associated with large invasive lava bodies [5], and inverted fracture networks with similar spatial patterns reported in the MFF could initiate as dikes [7]. Alternative models include meltwater freezing beyond the edge of the lava, high pore pressure freezing deformation, or injection of softened mud from the base of the flow. Our preferred hypothesis is invasive lava, but we continue to seek observations that would support or refute mud as the intruding fluid. We expect a variety of complex behaviors with melting ground below a thick lava flow.

Some of the disrupted terrains are similar to chaos terrain on Europa [8]. Although the materials and scales differ, the Martian terrains may provide an analog for the deformation mechanics occurring there.

Acknowledgements: This work was funded by MDAP grant NNH14AY77I and the Mars Reconnaissance Orbiter HiRISE project.

Figure 1: A-B) Tilted-facet terrain in Cerberus Palus (HiRISE anaglyphs from ESP_033965_1875/ESP_042576_1875 (7.5°N, 148.7°E) and ESP_025684_1885/ESP_026040_1880 (7.8°N, 149.3°E)). C) Disrupted terrain indicating uplift about level ground at top of image (Anaglyph from CTX B04_011377_1843 and B05_011522_1834 (3.4°N, 147.6°E)). D) Tilted facets in MFF (anaglyph from PSP_001856_1815/PSP_002700_1815 (1.4°N, 176.3°E)).