

ENIGMATIC FEATURES IN SOUTHERN ELYSIUM: EVIDENCE FOR SUBSURFACE LAVA-ICE INTERACTIONS L. Keszthelyi¹, W. Jaeger, C. Dundas¹, V. Bray², S. Sutton², ¹USGS Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001. ²Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

Introduction: HiRISE and CTX images have revealed a variety of puzzling features in southern Elysium Planitia that we propose formed by the subsurface interaction of lava and ice. Having a single process explain a wide variety of observations cleaves to Occam's Principle and could lead to important new insights into the nature of shallow ground ice on Mars.

Geologic Setting. Southern Elysium Planitia is part of the equatorial lowlands of Mars, covered by very young flood and plains lavas [1-5]. Phreatovolcanic features seen in the area require significant amounts of shallow groundwater/ice even though ice is not currently stable in the near surface.

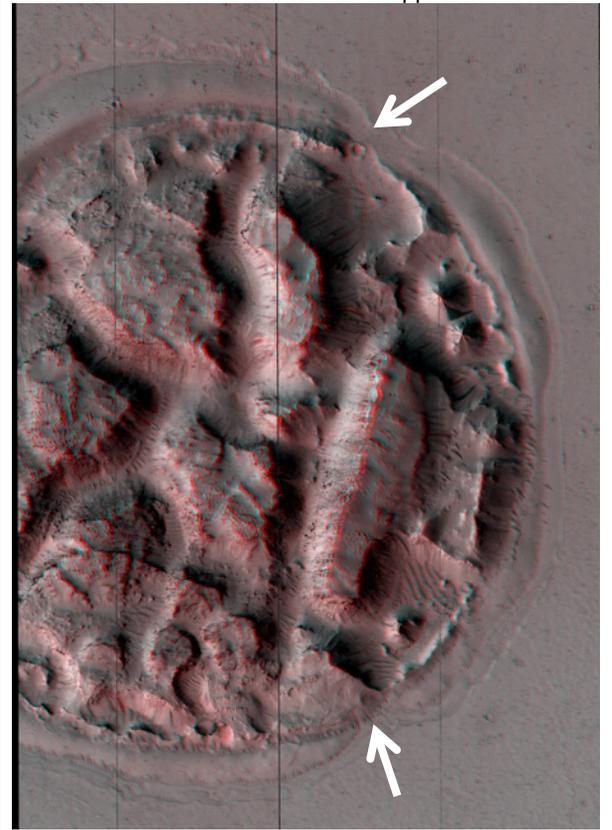
A Puzzling Crater: Our hypothesis was initially motivated by a crater filled with an enigmatic deposit (Fig. 1). The impact crater is surrounded by the youngest large lava flow on, the Amazonian Athabasca Valles Flood Lava (Unit Aav) [5]. The crater rim is very low but is overtopped in only two small sectors. The material within the crater stands 80-100 m above the lava but has deep fissures and depressions whose floors are at an elevation very close to the lava surface. We dismiss the idea that this feature formed by the erosion of a larger filled crater because (a) the crater filling material appears to be less resistant than the crater rim, (b) the contact between the crater rim and the fill is largely intact which should not be the case if the crater rim had eroded down and back, and (c) the crater rim does not appear heavily modified.

Instead, the geometry of the blocks and fractures suggests that the crater fill was uplifted but also lost a significant volume. We cannot precisely determine the pre-uplift elevation of the top of the crater-fill, but the material at the contact with crater rim seems minimally uplifted. This suggests the top of the fill was close to the elevation of the lava flow. The initial depth of this size crater should be ~500 m with a volume of 0.8 km³ [6]. Uplifting the crater fill by ~100 m would require the addition of ~0.3 km³.

The only geologically plausible fluids that could be injected into this crater to cause uplift are water, lava, or magma. There is no way to rule out magma as the intrusive fluid, but it is difficult to have magma stall at a depth of ≤500 meters (i.e., within the crater fill). Once that near the surface, the volatiles in the magma rapidly exsolve, leading to an eruption [7]. Therefore, we consider it unlikely that this is a laccolith.

An intrusive tongue of the Aav is more plausible. Based on images of a nearby crater, the sectors of the crater rim that were overtopped by the lava are large enough to feed the required volume of lava into the crater [8]. However, intrusive lava flows on Earth are almost exclusively found when lava comes into contact with water-rich unconsolidated sediments. Thus an intrusive lava flow in this Mars crater suggests that the sediment was softened by water, presumably ground ice melted by the heat of the lava. Furthermore, the volume loss and collapse features in the crater fill could be caused by the loss of water ice within the overlying uplifted sediments. Interestingly, the largest collapse areas in the crater fill are adjacent to where the lava overtopped the crater rim and the greatest heating might be expected.

Figure 1. Anaglyph from HiRISE images ESP_013249_1805 and ESP_038646_1805. Crater is ~2 km in diameter. Crater rim overtopped at arrows.



It may also be possible to create this uplift with just freezing groundwater. The heat of the Aav would raise the temperature of the ground underneath it to above freezing to a depth of tens to hundreds of meters [9]. Below that depth, water would freeze in the porespace, producing an impermeable barrier preventing water from penetrating deeper. Groundwater moving southward along the regional topographic gradient would encounter the crater fill which would be cold because it was not heated by lava. As the water entered the sediments and froze, it would expand. Water freezing in pore space would not produce the observed uplift. Instead, the gradual injection and freezing of groundwater could have created a pure-ice lens in a process analogous to pingos on Earth.

Observations of this one crater are insufficient to evaluate the relative merits of the “mega-pingo” and “invasive lava” hypotheses. In either case, the feature would be the result of subsurface lava-ice interaction.

Another Interesting Crater: Figure 2 shows a nearby crater that exhibits a variety of features supportive of the idea of subsurface lava-ice interactions.

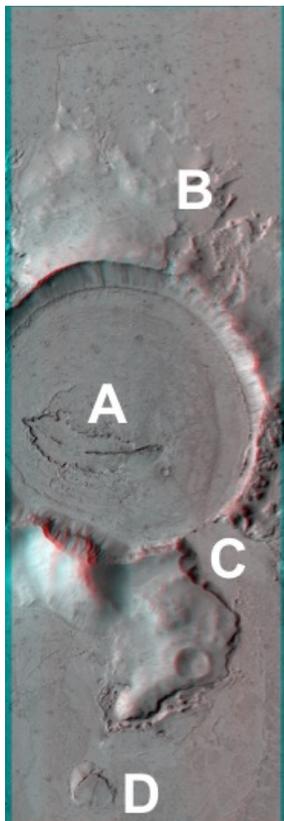


Figure 2. Anaglyph of ~6 km diameter crater made from HiRISE images ESP_028387_1790 and ESP_028532_1790. A volcanic vent with a partially drained perched lava pond (A) lies within the impact crater. The lava breached the crater on the SE sector (C). In this case we cannot rule out mechanical erosion as the dominant process. However, there is also significant erosion in the NE sector, where lava did not overflow the crater rim (B). Here we suggest that the heat of the lava fountains and lava lake melted ice in the crater rim which produced subsurface water flow through the ejecta.

The uplift labeled (D) in Figure 2 is especially interesting. The thickness of the uplifted block is much greater than would be expected for the upper crust of a lava flow, ruling out lava inflation as the formation

mechanism. In fact, the HiRISE images show a thin resistant cap on the block with much less consolidated material underneath, possibly crater-filling sediments.

This observation requires the uplift at (D) to have formed after the lava flow solidified. This timing is what would be expected if the uplift were caused by groundwater freezing after the ground returned to its normal subfreezing temperature. It is impossible to determine with certainty why groundwater would preferentially accumulate under this location, but a buried impact crater is one plausible explanation.

Discussion: There are many other observations in this region suggestive of subsurface lava-ice interactions. These include (a) scarps that appear to have formed by sapping at the contact between lava and older (presumably ice-rich) regolith, (b) kilometer scale uplifts of lava and mantling deposits that may have formed by either the “mega-pingo” or “invasive lava” processes, and (c) lava-filled craters without obvious vents within them or breaches in the crater rim. One possible explanation for these puzzling features is that invasive lava penetrated through the crater rim and filled the crater.

The source of the ground ice remains uncertain. It is possible that the flood lavas were emplaced during (or shortly after) large obliquity excursions, when models suggest atmospheric implantation of ice is possible [10]. It is even possible that there was significant snow/ice on the surface and that the Aav eruption was subice, generating jokulhuaps. Alternatively, the water may have been directly associated with the volcanic eruptions. This could be as precipitation out of the eruption column [11] or expulsion of deep water when the cryosphere is ruptured by rising magma [12]. The latter possibility is especially interesting since it means these locations could preserve indicators of the nature of Mars’ deep crustal aquifers, a possible extant habitable environment. What is certain is that these features will engender debate for years to come.

References: [1] Tanaka K. et al. (2014) *USGS Sci. Inv. Map*, 3292. [2] Vaucher J. et al. (2009) *Icarus*, 204, 418-442. [3] Plescia J. (1990) *Icarus*, 88, 465-490. [4] Jaeger et al. (2007) *Science*, 317, 1709-1711. [5] Jaeger W. et al. (2010) *Icarus*, 205, 230-243. [6] Stewart S. T. and Valiant G. J. (2006), *Meteor. Planet. Sci.*, 41, 1509-1537. [7] Wilson L. and Head J. W. (1994) *Rev. Geophys.*, 32, 221-263. [8] Hurwitz D. M. et al. (2010) *Icarus*, 210, 626-634. [9] Hamilton C. et al. (2011) *J. Geophys. Res.*, 116, E03004. [10] Mellon M. T. and Jakosky B. M. (1995) *J. Geophys. Res.*, 100, 11781-11799. [11] Plescia, J. B. (1993) *Icarus*, 104, 20-32. [12] Head J. W. et al. (2003) *Geoph. Res. Lett.*, 30, 1577.