HiRISE PERSPECTIVES ON THE FLOWS OF HRAD VALLIS, MARS

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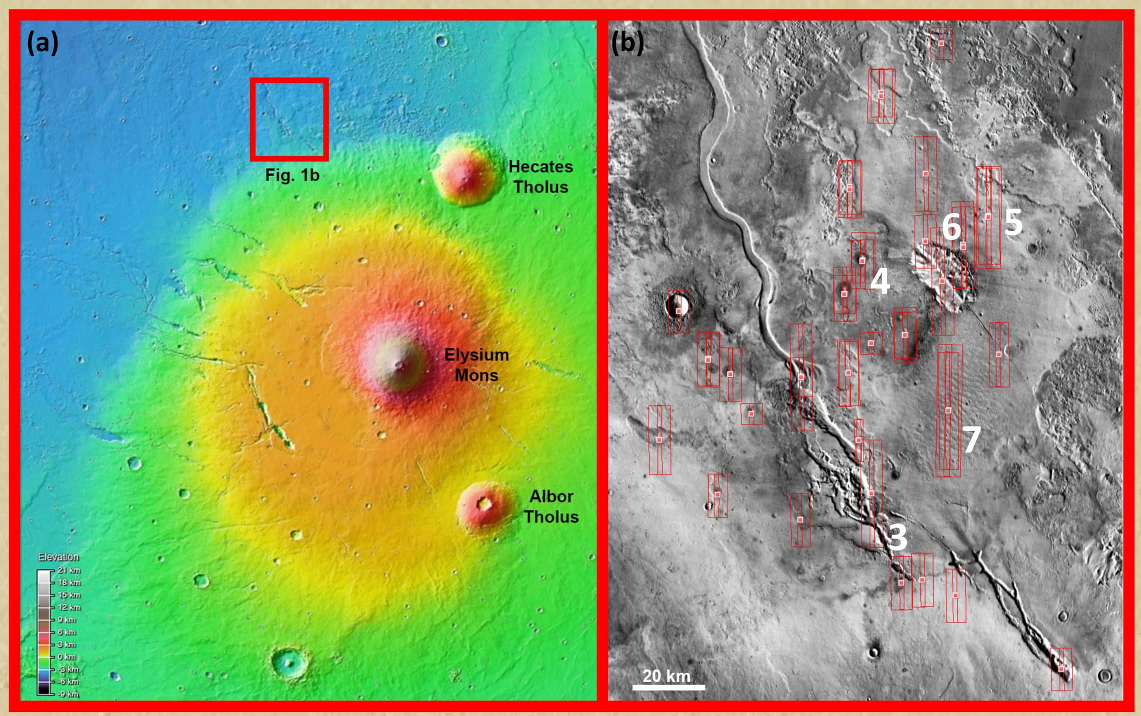

Fig. 1: (a) Location map for Hrad Vallis (red box), just north of Elysium Planitia. Background image is MOLA elevation data. (b) HiRISE coverage for Hrad Vallis. The field of view extends from 32° 43'N to 36° 00'N, 140° 25'E to 143° 33'E. Locations of other figures (numbers) are also indicated.

Introduction

The lobate material that flowed from Hrad Vallis (Fig. 1) has been studied for almost 30 years [1 - 3], and yet many aspects of the flow remain unresolved. Possible modes of formation include it being a lahar deposit [4, 5] or a flow generated by the intrusion of a sill into a water-rich substrate [6]. As part of a new 1:150K and 1:50K-scale mapping project for the U.S. Geological Survey, a reappraisal is under way of the properties of this material and the enigmatic craters within the flow, aided by the significantly improved spatial coverage over earlier data from CTX images (6 m/pixel) and an order of magnitude improvement in spatial resolution provided by HiRISE images (25 cm/pixel). Two discrete flows are identified (Fig. 2), with a lower flow unit originating from the eastern section of fractures and an upper flow from the western segment of the Hrad Vallis fracture system. Superposition relationships show that the upper flow formed second, and emerged from the same (western) fissure segment from which water originated. In contrast, the source of the lower (eastern) flow lacked associated water discharge.

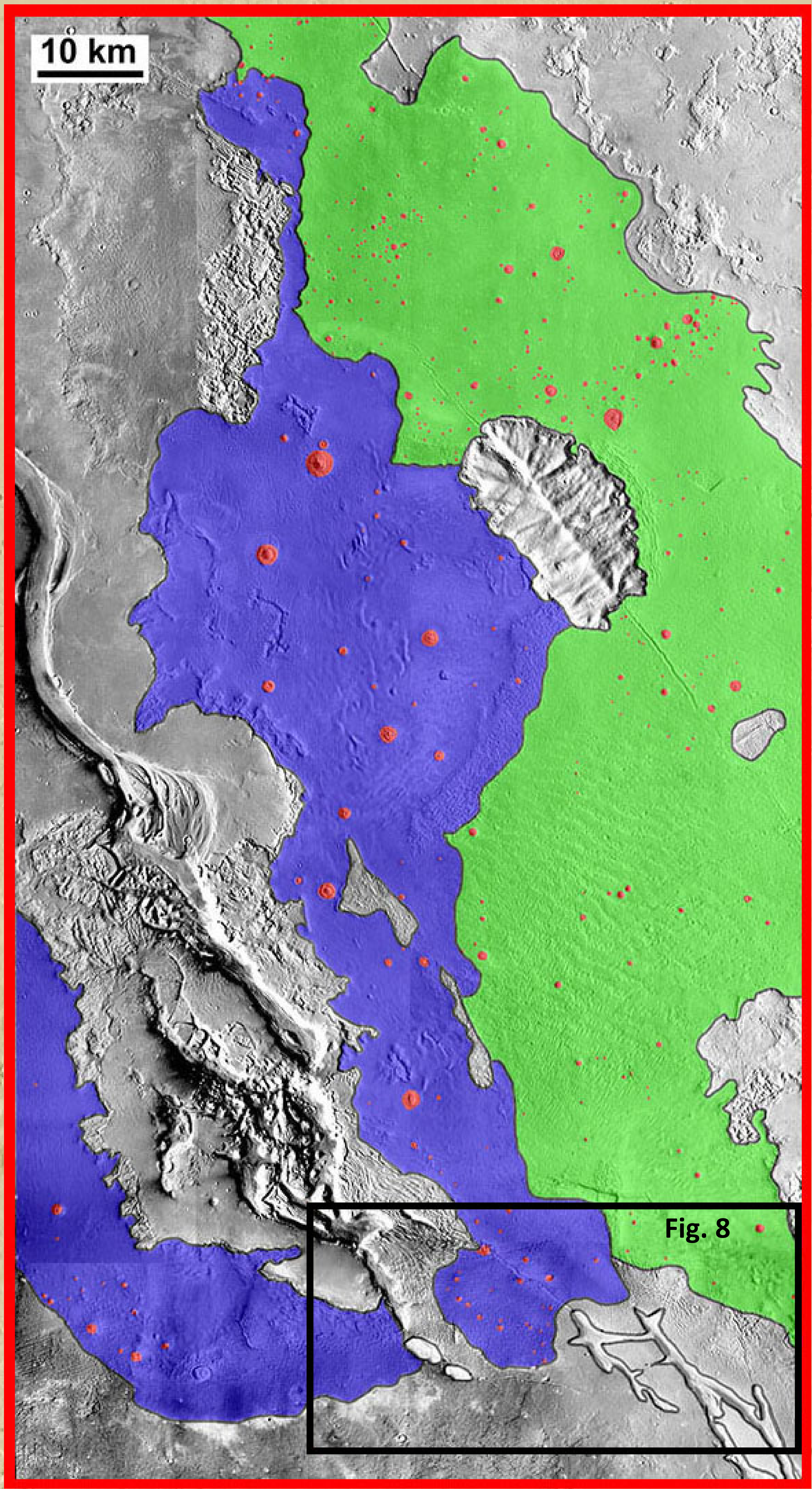

Fig. 2: Geomorphic map of the upper (blue) and lower (green) flows originating from Hrad Vallis. Red dots are the enigmatic craters discussed here. Base image is a mosaic of CTX images, centered at 34.5°N, 142.0°E. Location of Fig. 8 is indicated.

Key Questions Addressed with HiRISE Data

1. What were the physical properties of the flow? Sections of the source fracture (Fig. 3) show a large number of boulders >8 m in diameter within the exposed walls. These wall units are different from the layers interpreted to be lava flows as there is no discrete pattern to the block distribution. The occurrence of the boulders of this size implies that material within the flow would have taken a significant time to equilbrate in temperature [6], and the boulders would have remained hot during flow emplacement.

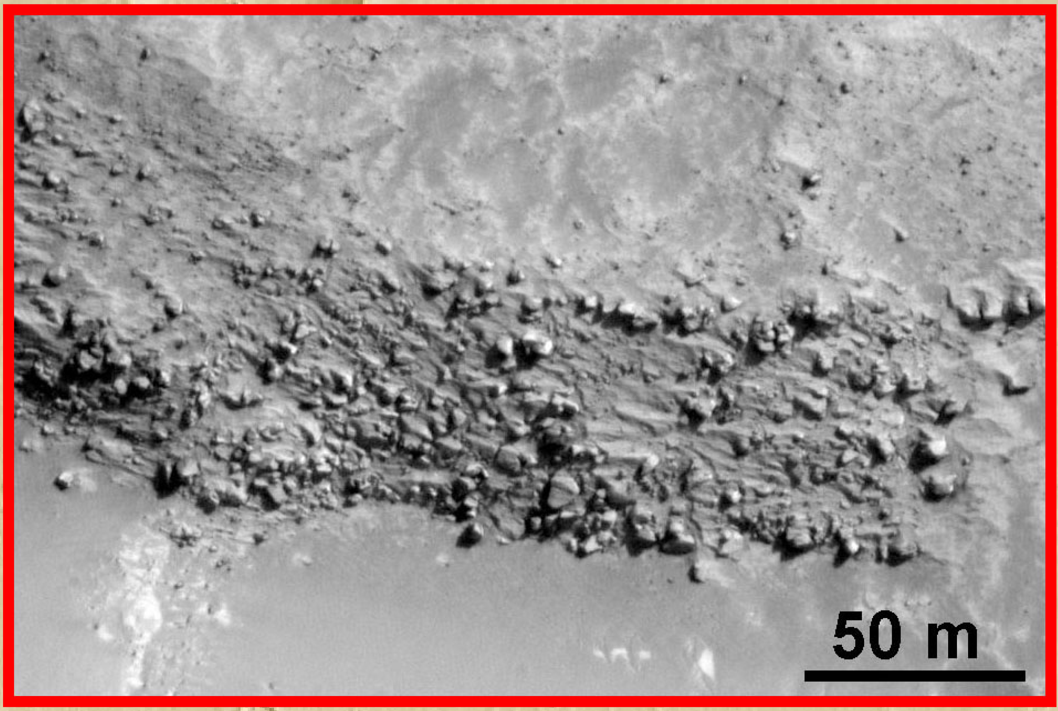

Fig. 3: The occurrence of numerous individual boulders displaying minimal sorting within the topmost layer of the wall of Hrad Vallis is consistent with the idea that the flow lobe is a mudflow that originated from Hrad Vallis [6], and that the boulders are "vent material". See Fig. 1b for location. Part of HiRISE image PSP_006169_2140. Note that the image has been rotated 180 degrees to aid the visualization of the scene.

2. What was the origin of the enigmatic craters on the flow? Morris and Mouginis-Mark [7] identified 12 unusual craters on the Hrad Vallis flows that have thermal anomalies (i.e., warm in nighttime THEMIS IR data, cold in daytime THEMIS IR data). A total of 42 unusual craters (mean dia. = 630 m, SD = 556 m) have now been identified on the upper flow, and 593 craters (mean = 271 m, SD = 77 m) on the lower flow have been mapped (Fig. 2). Only the larger (> 1 km dia.) craters possess thermal anomalies, but it is likely that there all of the craters had the same mode of formation. HiRISE images indicate that these thermal anomalies correlate with outcrops of many rocks 2 – 4 m diameter on the surface (Fig. 4). The distribution of these rocks lacks the radial pattern expected for an impact ejecta. Concentric features at the larger craters also show greater degree of blockiness.

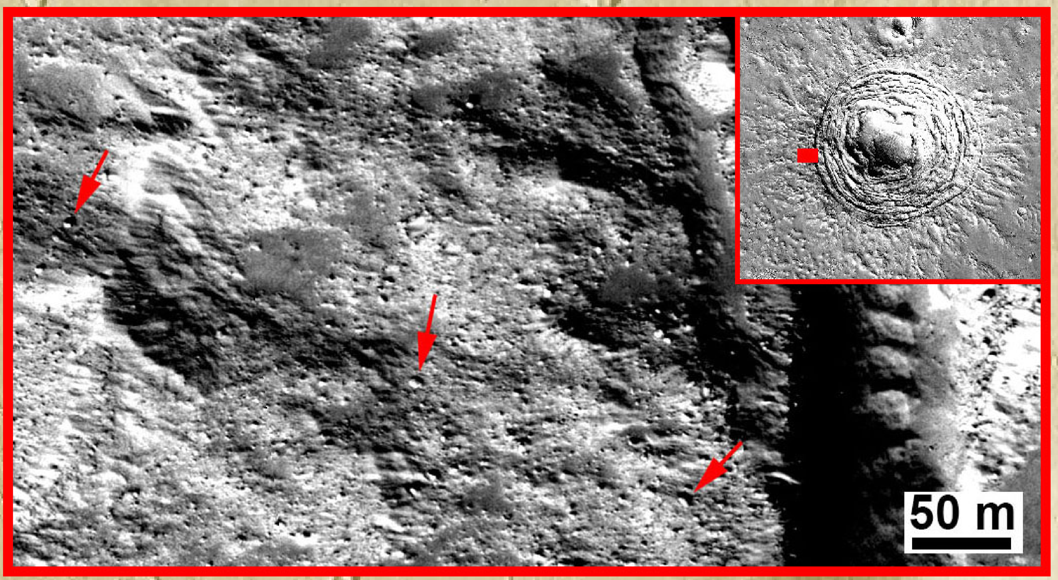

Fig. 4: Material surrounding one of the larger craters on the upper flow, which is one of the previously identified thermally anomalous craters [7]. Numerous boulders up to 4 m in diameter (red arrows) are visible on the western rim of the crater. Inset at the top right shows image location with respect to crater rim (red box). Part of HiRISE frame PSP_005879_2150.

On the downstream segment of lower flow, a concentration of these craters exists where the local slope is low. This area is also noteworthy due to the occurrence of three ~20 to 25 meter-high domes with summit craters (Fig. 5). The origin of these domes cannot yet be resolved, but possibilities include pingos or mud volcanoes [8 – 10]. Peripheral fractures are similar to those observed around the craters, raising the possibility that the domes are precursors to the thermally anomalous craters. A problem with the pingo model is the requirement to preserve the ice to produce domes that exceed 25 m height. Alternatively, these domes may be the equivalent to lava rises [11], which would imply post-emplacement inflation of the flow. However, no evidence for a period of protracted flow after the mud flow came to rest can be found which would argue against an inflation origin.

Fig. 5: Oblique view looking east of unusual pits and mounds on the distal portion of the lower flow unit. Height of the dome just right of center is ~25 m. See Fig. 1b for location. Digital elevation model derived from segments of HiRISE images ESP_016256_2155 and ESP_016322_2155.

3. How fast were segments of the flow moving? There is no indication that the lower lobe climbed up or over-rode Galaxius Mons (34.8°N, 142.3°E), which is the ~130 m high mountain embayed by the lower flow. No evidence of drain-off from the mountain can be seen (Fig. 6), suggesting that Galaxius Mons was not over-topped by the flows. However, the mountain's surface does appear to be mantled and the material does have contraction cracks.

Fig. 6: Northern boundary between lower flow (at left) and the mountain Galaxius Mons (at right). Note the lack of "drain-off" from the mountain to the flow and the relief of the fractures (~45 m deep) around the base of the mountain. See Fig. 1b for location. DEM derived from segments of HiRISE images PSP_007672_2155 and PSP_007883_2155.

Fig. 7: No evidence of dewatering of the flows north of Hrad Vallis can be identified. However, when viewed at HiRISE resolution many small mounds <200 m in diameter can be seen. The origin of these mounds remains to be resolved. See Fig. 1b for location. Part of HiRISE image ESP_025816_2145.

4. Signs of dewatering on the surface of the flow? The working hypothesis is that the flows from Hrad Vallis were formed as mud flows [1, 3, 6], although the amount of water contained within the flows remains unspecified. HiRISE data permit the inspection of these flows to search for signs that water was released from the flows after they came to rest. No small channels or other signs of "dewatering" have been observed on the surface of the lower flow (Fig. 7), suggesting either (a) a lack of free water during flow formation or (b) a process of water loss that was unable to affect the surface morphology.

Conclusions

The flows from Hrad Vallis represent a rare example of lobate materials that are unlikely to be lava flows. As other enigmatic flows (such as Zephyria Fluctus [12]) are identified on Mars, the Hrad Vallis flows may represent end-member examples of flows that were formed not by the eruption of magma but rather as viscous mixtures of water and sediment.

To better define the geology and geomorphology of the Hrad Vallis area, a new mapping effort is under way that will ultimately produce a new 1:150,000 scale map for the U.S. Geological Survey's Planetary Mapping Program. Principal among the areas to be mapped in detail is the area illustrated in Fig. 8, where ridged material surrounds the northern sides of the fractures, suggestive of viscous flow of material. Here the goal is to better understand the relative timing of the fluid release from the numerous segments of the fracture system that comprise the source area of Hrad Vallis.

Additional maps for areas of special interest will be created at different scales (1:50K to 1:250K) will also be produced over the next two years. One such a map would permit a spatial analysis of the enigmatic craters displayed in Fig. 2, as well as the origin of the domes seen in Fig. 5. In addition, mapping the distribution of ridges on the flow surface would allow details of the flow regime to be studied.

Fig. 8: The source area for the two flows that spread northward from the fractures at Hrad Vallis are particularly interesting because the relative timing of the fluid release still has to be resolved. Wilson and Mouginis-Mark [6] speculated that the flows were initiated when a volcanic dike originating from near Elysium Mons interacted with near-surface volatiles at the future source area of Hrad Vallis. Future mapping at a scale of 1:150,000 will be undertaken as part of the formal U.S.G.S. Planetary Mapping Program in an attempt to identify a chronology for the fluid release. See Fig. 2 for location. Mosaic of CTX images G19_025816_2145 and P03_002134_2157.

References: [1] Mouginis-Mark, P. J. (1985). *Icarus* 64, 265 – 284. [2] De Hon, R. A. (1992). *Proc. Lunar Planet. Sci. Conf.* 22, 45 – 51. [3] De Hon, R. *et al*. (1999). *USGS Misc. Map* I-2579. [4] Christiansen, E. H. (1989). *Geology* 17: 203 – 206. [5] Pedersen, G. B. M. and J. W. Head (2013). 44th *LPSC*, abstract #1514. [6] Wilson, L. and P. J. Mouginis-Mark (2003). *J. Geophys. Res*. 108, doi: 10.1029/2002JE001927. [7] Morris, A. R. and P. J. Mouginis-Mark (2006). *Icarus* 180, 335 – 347. [8] Dundas, C.M. *et al*. (2008). *Geophys. Res. Lttrs.* 35, LO4201, doi: 10.1029/2007GL031798. [9] Skinner, J. A. and A. Mazzini (2009). *Marine Petrol. Geol*. 25, 1866 – 1878. [10] Dundas, C. M. and A. S. McEwen (2010). *Icarus* 205: 244 – 258. [11] Walker, G. P. L. (1991). *Bull. Volcanol*. 53: 546 – 558. [12] Wilson, L. and P. J. Mouginis-Mark (2014) Dynamics of a fluid flow on Mars: Lava or mud? *Icarus*, in press.