EVIDENCE OF A MAGMATIC TRIGGER OF WATER RELEASE AND WIDESPREAD VOLCANIC ACTIVITY IN THE HEBRUS VALLES AND HEPHAESTUS OUTFLOW CHANNEL REGION, MARS.

S. Nerozzi[1], R. Spurling[1], J.W. Holt[1]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ (nerozzi@arizona.edu).

Introduction: Hebrus Valles (HV) and Hephaestus Fossae (HF) are well-preserved examples of Early Amazonian outflow channel systems carved into bedrock in SE Utopia Planitia, Mars (17-25 °N, 118-129 °E, Fig. 1). They exhibit a diverse set of morphologies indicative of formation by one or more liquid water outflow events, possibly initiated by magmatic intrusion, melting and cracking of the cryosphere [1-3]. However, little is known about their history, including both the origin and ultimate fate of the water and resulting sediments. This represents a significant gap in our understanding of geologic processes involving liquid water occurring in the Amazonian Period. Thanks to extensive coverage by recent datasets, it is now feasible to study the evolution of the HV-HF outflow channel systems with an integrated analysis of diverse and complementary data, including high-resolution visible imagery, radar sounding, and infrared imagery.

Methods: The initial task of this study is chronostratigraphic geologic mapping of the HV-HF region (Fig. 1). We integrate the analysis of a context camera (CTX, [4]) mosaic [5] and Thermal Emission Imaging Spectrometer (THEMIS, [6]) day and night mosaics [7]. This task is followed by the detailed reconstruction of the sequence of geological processes and events based on the identification of morphological and thermophysical facies in a subset of the study region. We employ impact crater statistical analysis to determine geologic unit and outflow channel ages.

We analyzed over 300 Shallow Radar (SHARAD, [8]) profiles over the entire study area. Clutter simulations based on high resolution DTMs allow us to distinguish returns that appear in the subsurface but originate from off-nadir surface relief [9]. We then calculated the bulk loss tangent of subsurface materials to constrain their possible composition [10].

Geologic mapping: We delineated the contacts between 8 geologic units, not including impact craters and the materials inside the outflow channels. The oldest unit in the study area is the *Nepenthes flow unit*, a complex layered volcanic and sedimentary unit that was previously identified with the same name in the adjacent Nepenthes Planum region [11]. On top of it lies the *Utopia lower unit*, which corresponds to a unit identified with different names in older geologic maps [2]. Moving up in the stratigraphic column, we found three additional lowland units: the *Utopia lowland unit*, the *Utopia lumpy unit*, and the *Utopia lobate unit*. We are currently testing hypotheses on the stratigraphic and genetic relationship between these units: (1) they represent two or three separate chronostratigraphic units, (2) they are three different morphological facies of the same chronostratigraphic unit, (3) they are three separate resurfacing stages of the same unit. This hypothesis testing exercise consists of refining of CTX image analysis and impact crater statistical analysis.

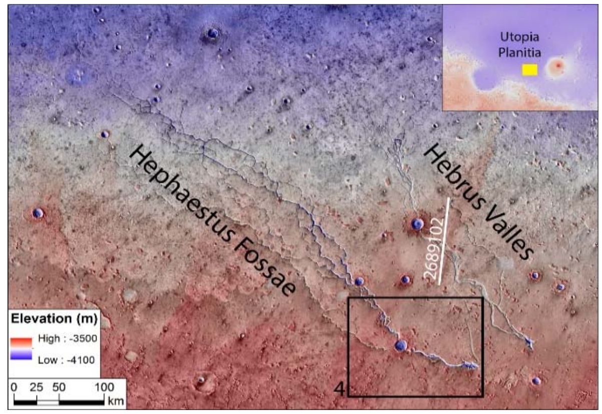

Figure 1: THEMIS IR Day mosaic overview of the study region in the broader context of Utopia. The white line indicates the location of the radar profile ground track in Fig. 3.

Three younger units overlie the Utopia units. In the NE corner of the geologic map lies the *Elysium volcanic unit*, which consists of volcanic flows related to Elysium Mons volcanic activity. To the south, we identified two additional units: the *Elysium platy unit*, which we interpreted to be volcanic in origin but distinct from the *Elysium volcanic unit*; the *Elysium chaos unit*, which may be a tectonic breakup of the *Elysium Platy unit*.

The outflow channels of Hebrus Valles and Hephaestus Fossae are carved exclusively on the *Utopia units*, which allows us to place a maximum age constraint of their formation at 3.2 ± 0.3 Ga (i.e., the age of the youngest of the *Utopia units*). However, the head depressions from where the channels originate may reach a lower unit that underlies the Utopia lower unit, perhaps the *Nepenthes flow unit*. We find a cluster of elongated ridges along the deepest reaches of the head depressions, which we interpret as the remnants of magmatic intrusions. We hypothesize that these intrusions first pressurized a confined aquifer by gradual displacement, then cracked a cryospheric seal allowing water to escape to the surface. Such formation mechanism implies that water flow may have been non-catastrophic in

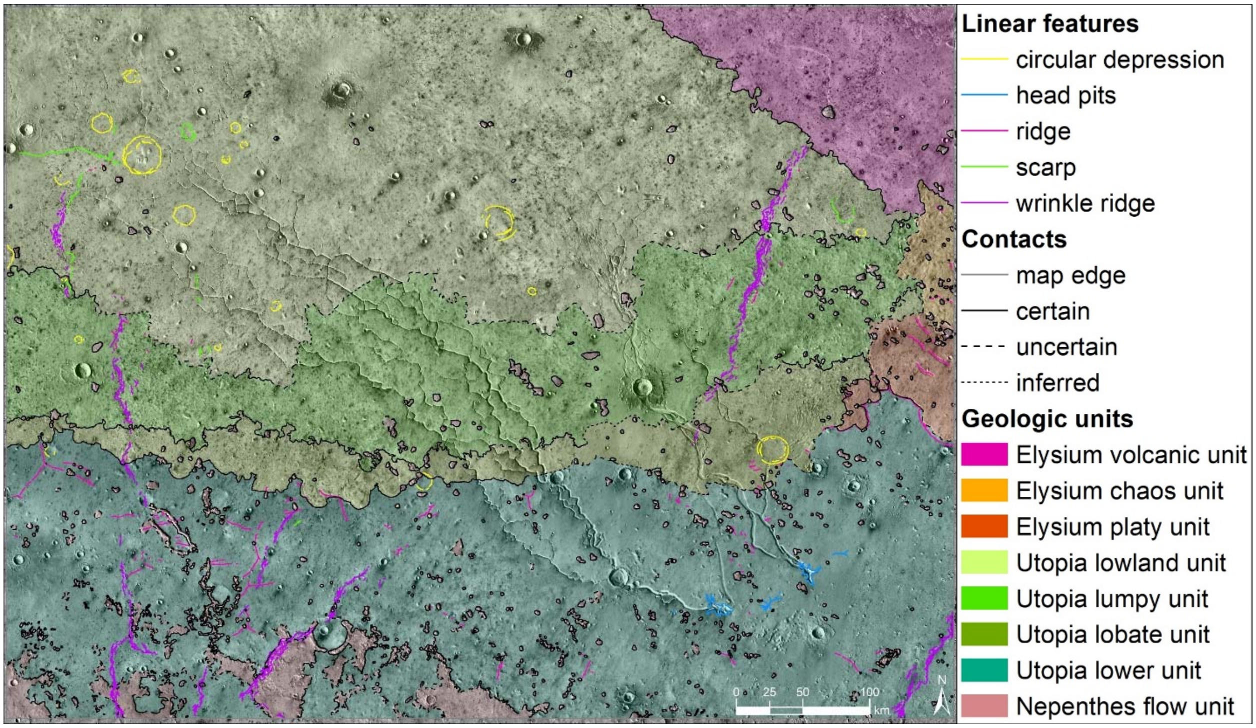

Figure 2: Preliminary chronostratigraphic map of the Hebrus Valles and Hephaestus Fossae region. The red circles delineate impact craters with diameters >2 km used for crater size-frequency distribution analysis.

nature and persisted for the long timescales (i.e., months to centuries) often involved in volcanic activity.

Radar sounding: Radar subsurface mapping reveals numerous clusters of shallow reflectors, which we divide into three categories based on their location. One large cluster of reflectors is associated with terrains of Hyblaeus Fossae and Granicus Valles and corresponds to the *Elysium volcanic unit*. At these locations we measured a wide range of loss tangents, spanning from ~0.01 to ~0.04, that are typical of basaltic lava flows [10, 12]. A second small cluster is located just west of the central region of HV (example profile in Fig. 3), where we measured a loss tangent of 0.012 ± 0.003, which is again typical of basaltic lava flows [10,12]. A third cluster is located to the SE of HV and reaches much larger depths than all the other radar observations in this region. We measure a low loss tangent of 0.0046 ± 0.0003, which suggests the presence of high-porosity and/or very low loss materials similar to those found in the Medusa Fossae Formation [12]. In general, radar sounding evidence points to widespread volcanism across the study region during the Amazonian period, further supporting the hypothesis of a magmatic trigger for the release of liquid water in the HV-HF region.

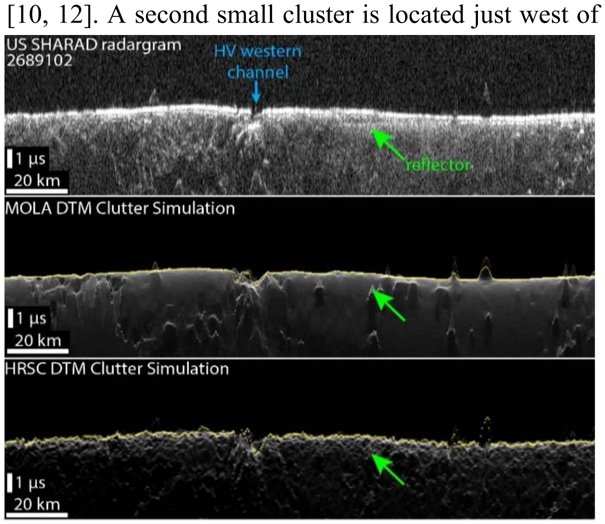

Figure 3: Sample of SHARAD profile showing a subsurface reflector. Clutter simulations below shows that only diffuse scattering is present at that location.

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