MEASURING SEDIMENTS OF WESTERN VALLES MARINERIS USING IMAGERY, RADAR, AND NEURAL NETWORKS TO CONSTRAIN PAST WET ENVIRONMENTS

I. Mishev (imishev@my.yorku.ca)[1] and I. B. Smith[1,2], [1]York University, Toronto, ON, Canada, [2]Planetary Science Institute.

Introduction: Light-toned layered deposits (LLD) are found across the plateaus and near to the rim of western Valles Marineris (VM), situated on top of Hesperian aged terrain [1-3]. These deposits exhibit fine scale layering, visible down to 1 meter resolution with the High Resolution Imaging Science Experiment (HiRISE, Fig 1). Characterizing LLD is essential to testing the hypothesis of their formation and may constrain the timing and duration of water activity in this region.

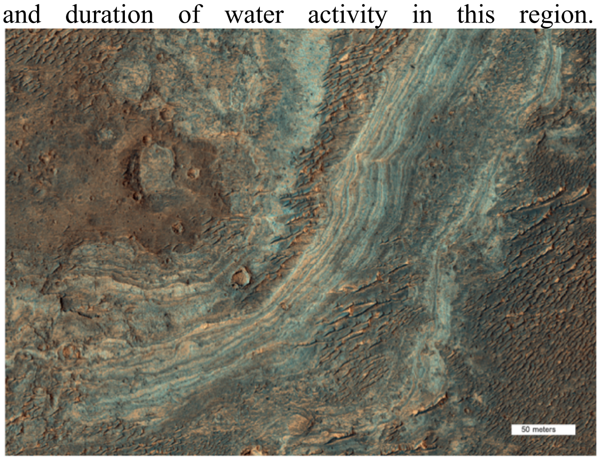

Figure 1: LLD outcrop displaying fine scale, complex layering with bedforms onlapping the horizontal surfaces. Located on the southern plateau of Ius Chasma (yellow star in Fig. 3).

Recent Developments: In our initial survey, we detected regions on the plateaus where layering is scarce but there is a thick unit of material overlaying the bedrock. These are thought to be related to the LLD because of their proximity and transitional nature. Using instruments onboard the Mars Reconnaissance Orbiter, we mapped the extent of the LLD and other units over the western region of VM. We have identified and mapped three large-scale morphological regions on the plateaus of western VM and have found the bulk permittivity of the materials is ~3, supporting the interpretation of sedimented, low-density ash that has been reworked to varying degrees.

In addition to the large-scale regions, we have identified small-scale surface bedforms known as deltoids, during the HiRISE imagery investigation. The deltoids appear to form or erode from the LLD and the related massive units, and their presence may give clues to their composition.

Large Scale Regions:

A) Widespread Layering. These regions exhibit complex layering (Fig. 1, orange in Fig. 3) that extends across vast unbroken stretches, and are accompanied by the largest concentration of radar reflections. Additional evidence of fluvial morphologies and overland flow exists in these regions [3].

B) Massive Unit with Isolated Layers/Pseudolayers. Regions with intermittent or occasional layering, often concentrated directly adjacent to the rims of the plateaus (Fig. 2, green in Fig. 3). Layers appear less pronounced and discontinuous, but radar basal reflections are contiguous throughout and into neighboring units.

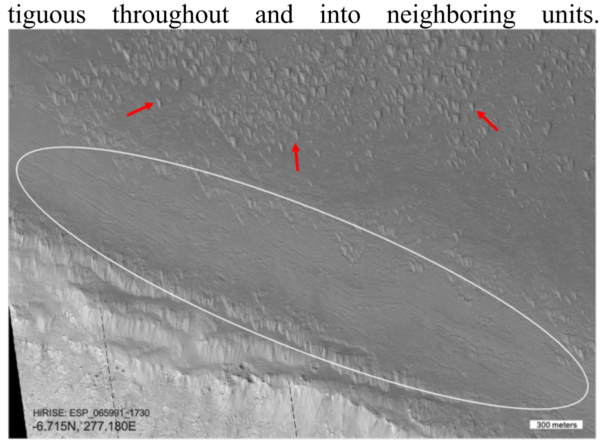

Figure 2: Massive unit with isolated, layers/Pseudolayers on the northern plateau of Ius Chasma (blue star in Fig. 3). Layering near to the rim is circled for emphasis. Red arrows denote deltoids

C) Unlayered Massive Unit. These units are bland on the surface and are only identified by the density of SHARAD basal reflections found within them (yellow in Fig. 3). Radar investigations show that the massive unit is contiguous with the LLD, units A and B.

Formation Hypothesis: The formation mechanism and history of the LLD is currently under question. One hypothesis that we are investigating is that the LLD are thought to be composed of pyroclastic ash fall. The relative proximity to multiple large volcanos suggests that nearby eruptions emplaced material in vast amounts, consistent with other locations on Mars [5-6].

Morphological Map of Western VM:

Widespread evidence of fluvial and lacustrine settings [1-3] correspond spatially to the LLD, where geochemical alteration products are also present. Thus, after and during emplacement, the material interacted with water to form layers, channels, and alteration minerals. We hypothesize that the difference between regions A, B, and C, is access to water: areas with widespread layering formed in ponded water, whereas regions with moderate layering experienced intermittent or one-time water. Regions absent of layers were dry.

We combined the findings from the radar and imagery investigations to create a map of Western VM that shows the relationship between the LLD, the massive units, and the basal reflections (Fig. 4).

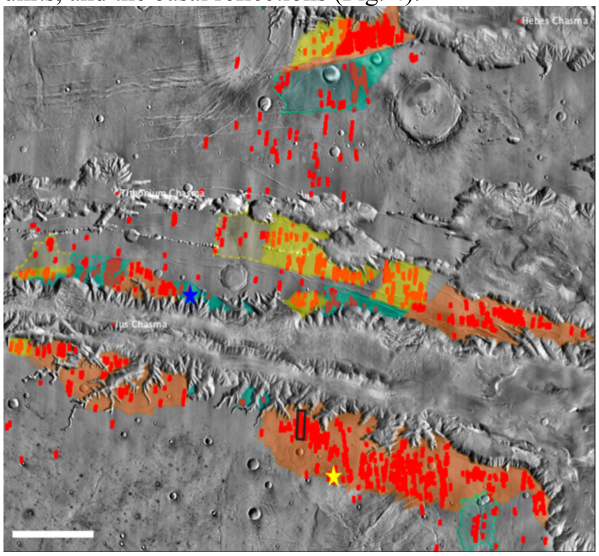

Figure 3: THEMIS-Daytime image of western VM. Red lines show SHARAD basal reflections. Widespread layering displayed (A) in orange. Massive unit with Isolated Layers/Pseudo layers (B) shown in green. Unlayered massive unit (C) shown in yellow. Dashed lines indicate regions where extent of unit boundaries are not defined. Yellow Star = Fig. 1, Blue Star = Fig. 2,4. White = 100 km.

Small Scale Objects Neural Network: Deltoids are abundant throughout western VM, and are believed to be composed of the same material that comprise the LLD. To test this hypothesis, a neural network was implemented to locate, map and determine their characteristics. The size of deltoids (meters to tens of meters) requires HiRISE images to provide a sufficient resolution for use with a Region-based Convolutional Neural Network (Mask RCNN).

Mask RCNN is a neural network framework which utilizes a ResNet101 backbone [7]. It has been implemented into an open source package built on Keras and Tensorflow, which we customized for our purposes. Mask RCNN performs instance segmentation on each individual deltoid, allowing for analysis of the objects which wouldn't be possible with a simpler algorithm, such as semantic segmentation. To our knowledge, this is the first example of instance segmentation being employed on HiRISE imagery.

Training and Preliminary Results: 20 HiRISE images featuring deltoids were cut into tiles of 512x512, and 320 of these tiles were randomly selected and annotated manually. 260 tiles were used for training, and an additional 30 tiles each were used as a validation subset and test subset, respectively. Training was accomplished using a regime of 100 epochs, a mini-batch size of one (due to GPU limitations), and 260 steps per epoch. To ensure overfitting of the data was minimized, all results were obtained using an early stopping approach, halting training after 18 epochs.

Preliminary results shown below (Fig. X) indicate fairly accurate detection of the majority of deltoids for a particular tile from HiRISE image ESP_065991_1730. A mean average precision (mAP) was calculated to 0.6955 using built in evaluation metrics available in the Mask RCNN framework.

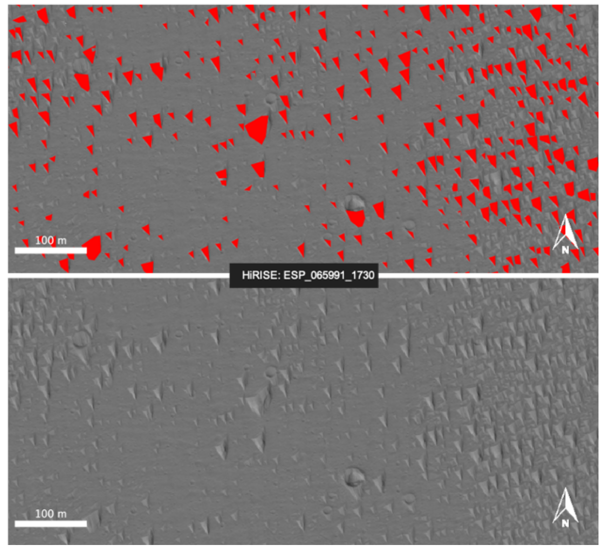

Figure 4: Above: Masked deltoids detected with Mask RCNN Neural Network. Below: Same image without masks shown for comparison.

Deltoids are a major surface feature on VW, occupying large portions of land. Understanding their characteristics on a large scale will reveal insights not apparent when looking at individual instances. A complete mapping of all deltoids within VM is to be completed, along with searches into regions outside of VM, to locate other instances of these features. Additional framework is being developed to determine the size, direction, and density of deltoids within a given region to give us a deeper understanding of their characteristics. Doing this task manually is not feasible, and shows the value of neural networks in planetary sciences.

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References: [1] Le Deit et al. (2010) *Icarus, 208, 2,* 684–703. [2] Weitz et al. (2008) *GRL, 35,* L19202. [3] Weitz et al. (2010) *Icarus, 205, 1,* 73–102. [4] Smith et al (2019) *LPSC L, Abstract #2713* [5] Kerber et al. (2012) *Icarus,* 219, 1, 358-381. [6] Runyon et al. (2020) LPSC LI, Abstract #1083. [7] He et al. (2017)