MARTIAN POLAR STRATIGRAPHY FROM HIRISE STEREO TOPOGRAPHY. P. Becerra$^1$, S. Byrne$^1$, S. Sutton$^1$, J. D. Pelletier$^2$, M. Sori$^3$, K. E. Herkenhoff$^2$, and the HiRISE Team. $^1$Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA. becerra@lpl.arizona.edu, $^2$Department of Geosciences, University of Arizona, Tucson, AZ, USA. $^3$U.S. Geological Survey, Flagstaff, Arizona, USA.

Introduction: The North and South Polar Layered Deposits of Mars (NPLD and SPLD) are broad sheets of water ice and dust. They are dissected by deep troughs that allow a view of their inner structure (fig. 1), and are composed of layers of varying thicknesses that have long been recognized to represent a record of recent climate change on Mars [1].

One of the longest-standing questions related to these deposits was recently re-affirmed at the 5th International Mars Polar Science and Exploration Conference: “What chronology, compositional variability, and record of climatic change is expressed in the stratigraphy of the PLD?” [2]. In order to attempt to answer this question, our first step is to accurately describe this stratigraphic record. This important step has been limited in the past due to the lack of layer-scale topographic data, which forced the use of quantities such as brightness to describe a layer.

The Shallow Radar instrument (SHARAD) has detected reflectors within the NPLD that are interpreted to be depositional layers [3], and could be correlated to the visible strata [4]. This implies that, at least in the NPLD, the layers are laterally continuous, and form a coherent record of depositional conditions. Past researchers have attempted to extract periodic signals from stratigraphic sequences constructed from the brightness of layers observed in images of the PLD scarps [1,5-11]. They created virtual ice cores, plotting layer brightness from Mars Orbiter Camera (MOC) images vs. depth taken from the Mars Orbiter Laser Altimeter (MOLA) [5-7]. These studies generally agree that there are dominant stratigraphic wavelengths of ~30 m [6,8] and ~1.5 m [7,8] in the upper 300 m of the NPLD. The main problem with past studies is that the observed brightness of exposed PLD layers is a complicated product of slopes, frost retention, albedo, surface texture, and most importantly a sublimation lag deposit that mantles the exposures [10]. Therefore, it is not clear how brightness relates to intrinsic properties of the layers themselves, if at all.

Thanks to the advent of high-resolution images and Digital Terrain Models (DTMs) from the High Resolution Imaging Science Experiment (HiRISE), significant advances in the accurate description of the PLD stratigraphy are now possible. Recent work used these data to map morphological properties of discrete layers within a sequence [8, 9]. Fishbaugh et al. [8] created the first high resolution stratigraphic column of the NPLD based entirely on morphological properties, categorizing layers into marker beds and thin layer sets based on texture and apparent protrusion from adjacent materials on the wall. The authors likely identified the structures responsible for both the 30 m and the 1.6 m signals. Limaye et al. [9] made similar stratigraphic columns based on bed thickness and provided the first high-resolution stratigraphic mapping of SPLD layers. The disadvantage of such discrete layer mapping is that there are no continuous depth-varying quantities that can be examined with spectral analysis tools.

In this study we perform a comprehensive morphology-based description of PLD stratigraphy, examining depth-varying properties of the layers that have previously not been studied, and correlating stratigraphic features throughout the entire extent of each PLD (fig. 2). We are creating a continuous stratigraphic column that is representative of the uppermost few hundred meters of each PLD, which we can later scrutinize with spectral analysis, in order to attempt a correlation with periodic changes in orbital parameters that are likely to have caused climate variations. The morphological quantity we choose is a measure of how the protrusion of strata from the scarp face varies with depth (extracted from HiRISE DTMs as described below). This quantity can be taken as a proxy for a layer’s resistance to erosion [11].

Fig. 1. HiRISE PSP_001738_2670. Left: Layer exposures on a scarp on the NPLD. Right: Blow-up of highlighted area showing slumping lag deposits.

Fig. 2. MOLA topography of Martian PLD. Green Stamps: Available HiRISE stereo data. Red circles: Currently available DTMs analyzed in this study. Blue circles: Sites of DTMs that are currently under production for this study.
Data and Analysis: The 1 m/pixel DTMs are made from 30 cm/pixel HiRISE stereo pairs using the procedure described in [12]. Figure 2 shows the sites we have selected for study. Our main objective when selecting these locations was to maximize geographic coverage. The majority of these sites were chosen based on the current availability of stereo pairs and DTMs. However, we are also targeting specific locations for stereo imaging that may be more convenient for this study, based on exposure of layers and position relative to our current study sites.

In each DTM, we perform a best linear fit to topographic profiles within a local “window” (~200 m) along the scarp, and compute the difference between the actual topography and the fit at each point [11] (fig. 3). To reduce noise in the protrusion signal, we extract sets of 5 parallel protrusion profiles offset 10 m from each other. We take the average of each set, and create a representative profile for that location. We can then compare and cross-correlate profiles from different locations within a DTM, and from different DTMs across the NPLD. This allows us to map a continuous, protrusion-based stratigraphy, representative of the full extent of the upper units of the PLD.

Results:
Layer Correlation and Stratigraphy: As an initial test of our method, we extracted profiles from different locations within a DTM, and cross-correlated them to attempt to match layers from one location to another. The result is shown in the left panel of figure 4. As expected, the correlation between two profiles a few hundred meters apart along the same scarp was excellent, and we were able to identify the same layers, and similar patterns of protrusion in both profiles. In addition, we identified the layers mapped by [8] in the profiles taken from site N3 (fig. 4). This allowed us to connect our work with the results of previous studies, and confirm the morphology of the marker beds and thin layer sets described by [8].

Fig. 3. Left: HiRISE DTM with location of protrusion profiles. Each profile represents the average “noise-reduced” profile for that location. Center: Schematic of the calculation of layer protrusion from the local scarp-face. Right: Average protrusion profile extracted from location P1 on site N3.

Fig. 4. Left (plotted lines): Profile P2 from site N3 (fig. 3) shifted to match layers in P1. Colored bands relate to the center panel in this figure. Center: Stratigraphic column from [8] with locations of Marker Beds and Thin Layer Sets in site N3. Right: Result of cross-correlating protrusion profiles from sites N1 and N3. Locations of Marker Beds identified in N3 are shown along side locations of the same beds in N1. Currently, we are correlating protrusion patterns from one DTM to another in different locations throughout the NPLD, and will later extend the same procedure to the SPLD. Figure 4 shows the result of cross-correlating profiles from sites N1 and N3. These preliminary results show that we are able to correlate, to a reasonable approximation, the protrusion pattern observed in site N3 to site N1, including the marker beds identified in [8]. We are refining our techniques to use dynamic time warping algorithms in the cross-correlation of protrusion signals, following the work of [13]. Once correlated, the results of several DTMs will be merged to produce a single stratigraphic record that eliminates gaps due to local unconformities, assuming missing strata are preserved elsewhere.

Preliminary Spectral Analysis: Byrne et al. [11] performed wavelet analysis on single, non-noise reduced protrusion profiles of the NPLD at five locations, and found a dominant wavelength of ~40-45 m, as well as multiple secondary signals. We will use this method to analyze the representative column that we build for each PLD, and search for connections with changes in orbital and rotational parameters.