THE EXPOSED STRATIGRAPHY OF THE MARTIAN SOUTH POLAR LAYERED DEPOSITS

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Introduction: The polar regions of Mars are characterized by kilometers-thick deposits of stratified water ice and dust, which are directly observable remotely because of spiral troughs that reveal their inner structure. The formation of these Polar Layered Deposits (PLD) is theorized to have been driven by astronomical forcing [e.g., 1]. In recent years, observations of exposed bedding in the troughs supported this theory for the northern PLD (NPLD) [2], showing the stratigraphic record to be consistent with climate variations forced by the planet's insolation history and a variable ice accumulation rate [3,4]. In addition, crater size-frequency analysis [5] and spectral reflectance [6] show that the surface of the NPLD is only a few kyrs old.

In contrast, the southern deposits (SPLD) appear to be at least an order of magnitude older [7,8], with exposed strata that are thicker, darker, and significantly more eroded than in the NPLD [9–11]. In addition, the prospect of tying a climate record to the SPLD is significantly hindered by the fact that the solutions for Mars' past orbital evolution become chaotic earlier than ~20 Ma [3], which is younger than the SPLD surface age. These problems have resulted in fewer studies of the SPLD in comparison to its northern counterpart.

Here, we map the SPLD stratigraphy at high resolution by using an expanded dataset of HiRISE Digital Terrain Models (DTMs). We search for dominant periodicities in the stratigraphy, as well as attempt a correlation between exposures at different regions of the SPLD to determine if a consistent climate signal is recorded throughout the study area, as was demonstrated for the NPLD [12].

Methods: We use data analysis methods similar to those used for the NPLD by [2]. The data is a set of 8 HiRISE-based DTMs [13] and orthorectified images spread out across the SPLD (Fig. 1). As in [2], we extract local slope (at the vertical resolution of the DTMs, ~1m), and bed protrusion (a property explained in [12] and which is a proxy for resistance to erosion) from the DTMs; and from the orthoimages we extract reflectance profiles. Five individual linear profiles taken ~10 m apart along strike are averaged to minimize noise due to roughness or local erosion effects. The average protrusion profiles for each site are shown in Fig. 2. The maxima and minima of the linear profiles are then mapped in the HiRISE data to observable layers or protruding beds in the trough wall, and where possible, will be traced through CTX images to reveal their extent along a particular trough.

We visually compare topographic and reflectance profiles through 8 different SPLD sites (e.g. Fig. 2) and we will use dynamic time warping (DTW) to quantify the statistical significance of potential correlations between different sites. The DTW method quantitatively tunes a time-varying function to another to test for possible covariance between the two (here, depth is a proxy for time) and has been validated for use in the Mars PLD [14].

We search for periodicities in the continuous linear profiles using Fourier and Wavelet Analysis. The Fourier and time-varying wavelet power spectra (WPS) reveal any dominant periodic forcing frequencies in the data, providing another tool for correlating strata from different sites to each other and informing future investigations into the putative orbitally forced deposition of the SPLD.

Preliminary Results: Protrusion profiles for 7 of the 8 SPLD sites are shown in Figure 2. The stratigraphic exposure at site S1 largely does not overlap in elevation range with any other site and thus will likely not correlate with the stratigraphy of any other site [10]. Potential correlations between the remaining 7 sites vary in significance. Some site pairs (e.g., S2 and S5 in Fig. 1a) display similar protrusion profiles that are suggestive of a common stratigraphy, while other site pairs (e.g., S3 and S6) have starkly different stratigraphic expressions of protrusion and reflectance despite their common elevation and relative proximity. Preliminary wavelet analysis yields results that seem to be consistent with what we observe in Fig. 2 (example WPS for S0 are shown in Fig. 3). S0 and S4 have very similar WPS patterns in protrusion, in which the larger wavelength dominates for a significant portion of the profile. S3 and S6 have similar dominant wavelengths in protrusion (20 m and 15 m), despite different amplitudes. Except for S2, the lower 5 sites appear to have larger dominant wavelengths (S0 = 72 m, S4 = 102 m, S5 = 47 m, S2 = 34 m, S7 = 135 m). A similar grouping holds for the WPS of the slope profiles: The lower five sites show dominant wavelengths between 2–5 m; however, S6 also exhibits this periodicity, while S3 does not. In the case of brightness, the lower 5 sites, with the exception of S7, show periodicities between 5–11 m, while S3 and S6 do not show any particular strong periodicity.

We can speculate that the two sets of profiles correspond to two different periods of accumulation, which may be separated by more than a few million years. This speculation agrees to a certain extent with the three broad-scale stratigraphic units of [10]. Although these authors mapped exposures of similar units that they correlated based on morphology, a quantitative correlation is missing, and it would provide solid evidence for Promethei Lingula (PL) having been deposited during a single epoch of climate variations.

The exposure stratigraphy of the SPLD thus appears more complex and less consistent than that found in the NPLD. In fact, ongoing radar analysis suggests these difficulties may exist in layers that are not exposed at the surface as well [15].

Future Work: An expanded dataset of DTMs will significantly help our work, as it did for the NPLD. We have targeted new areas in the SPLD for DTM creation. In particular, a DTM in Ultima Lingula (near site S2) will help us define whether this represents an entirely different stratigraphic unit, or if it can be correlated to the Promethei Lingula Layer sequence (PLL) of [10]. Additionally, there is only one DTM in the highest areas of the SPLD (S1), so we have also targeted this area to obtain a complete picture of the accumulation history of the SPLD.

Further in the future, we plan to statistically compare the dominant wavelengths in the stratigraphy to the possible orbital scenarios before 20 Ma proposed by [3]. As was done for the north by [2], and for equatorial deposits by [16], we will find the average ratio of wavelengths across all stratigraphic data and compare this ratio with those of the many possible oscillations of the average insolation [3].

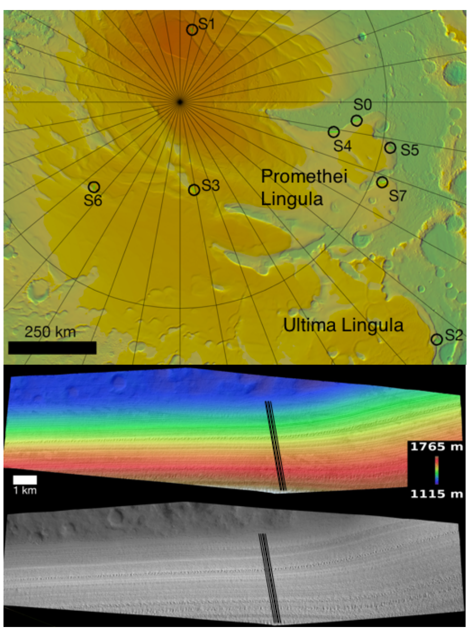

Fig. 1. Top: MOLA map of the SPLD with study sites and two major Linguli indicated. Center: HiRISE DTM of site N0. Bottom: Orthoimage of the same site. Lines indicate location of extracted linear profiles.

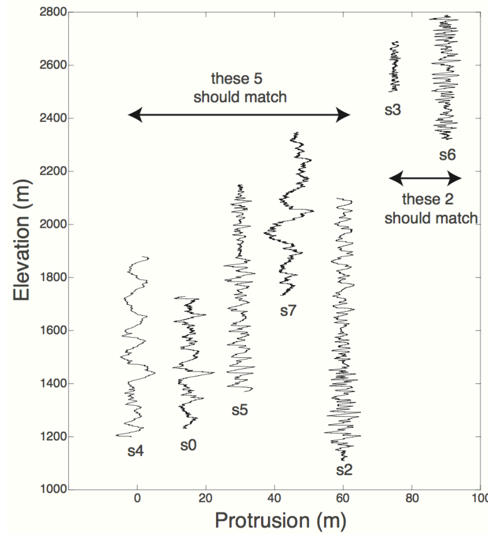

Fig. 2. Average protrusion profiles as a function of elevation for 7 sites in the SPLD. Profiles are offset in increments of 15 m on the x-axis for better visibility.

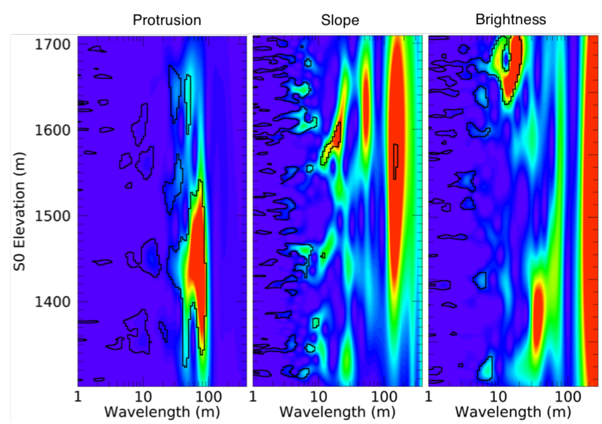

Fig. 3. Wavelet Power Spectra of the protrusion, slope, and brightness profiles of site N0. Warmer colors indicate higher power. Black lines are contours denoting the 95% confidence level over red noise (see [2] for details).

References

[1] Laskar et al. Science (2002) [2] Becerra et al. GRL (2017) [3] Laskar et al. Icarus (2004) [4] Hvidberg et al. Icarus (2012) [5] Landis et al. GRL (2016) [6] Brown et al. Icarus (2016) [7] Herkenhoff et al. Icarus (2000) [8] Koutnik et al. JGR (2002) [9] Byrne and Ivanov, JGR (2004) [10] Milkovich and Plaut, JGR (2008) [11] Limaye et al. JGR (2012) [12] Becerra et al. JGR (2016) [13] Kirk et al. JGR (2008) [14] Sori et al. Icarus (2016) [15] Whitten et al. AGU (2017) [16] Lewis et al. Science (2008).