**SEARCHING FOR A CLIMATE SIGNAL IN MARS' NORTH POLAR DEPOSITS.**

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**Introduction:** The stratigraphy of the icy layered deposits on Mars' poles has long been hypothesized to record recent climatic changes due to temporal variations in the planet's orbital and rotational parameters [e.g. 1,2]. In this study we explore the possible climatic record of the North Polar Layered Deposits (NPLD), by analyzing the dominant periodicities of a stratigraphic column that was built based on the topographic expression of the layers.

The NPLD have been shown by the Shallow Radar (SHARAD) instrument on MRO to be composed of laterally continuous depositional layers [3]. These layers are viewable in a series of spiraling troughs that dissect the NPLD (fig. 1a,b). Past studies have relied on the observed brightness of exposed layers to construct stratigraphic signals and analyze their periodicities [4-8]. Most of these agree that there is a dominant stratigraphic wavelength of 25-30 m in the upper 300 m of the NPLD [4,5], although wavelet analysis of similar data [6] showed little evidence for any signal in that wavelength range. However, brightness has been shown to be an unreliable stratigraphic quantity, as it is heavily influenced by a sublimation lag that slumps over the deposits, and thus may not be related to the internal structure of a layer [9-12]. Here we use a stratigraphic column that we constructed based on the protrusion of layers from the average slope of a scarp, which we take to be directly related to a layer's resistance to erosion. We have shown that this quantity is continuous throughout the NPLD and is better suited to describe the stratigraphy than observed layer brightness [11,12]. We use wavelet analysis to explore the periodic nature of this signal and its relationship to Mars' historical insolation signal, as wavelet transforms are able to detect changes with depth in the dominant periodicities.

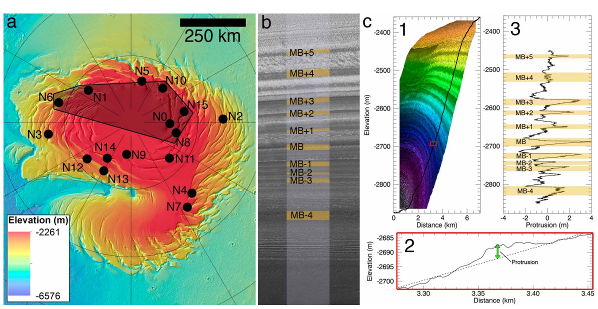


**Fig. 1.** (a) Topographic map of the NPLD. Black dots indicate study sites in [10,11]. The delineated area is the minimum for which the column in 2a is valid. (b) HiRISE image of the scarp wall at site N0 with Main Sequence layers labeled. (c) Extraction of protrusion profile at site N0. 1: Elevation profile over vertically exaggerated DTM. 2: Protrusion measurement. 3: Resulting protrusion profile for site N0 with Main Sequence layers labeled.

**Data and Methods:**

*Stratigraphic Column*

We used Digital Terrain Models (DTMs) made from High Resolution Imaging Science Experiment (HiRISE) images to extract profiles of layer protrusion vs. depth at sixteen different scarp locations throughout the NPLD. Protrusion is measured as the vertical difference between each point in a 1D topographic profile of the scarp taken from the DTM, and a local linear fit to the scarp wall (fig. 1c). We correlated six protrusion profiles of different sites to each other, and constructed a continuous, protrusion-based stratigraphic signal that represents the topmost 400 m of the NPLD in at least 9% of its area (fig. 1a). This column (fig. 2a) displays the relative elevation of the most prominent layers in this sequence (which we term the Main Sequence [11]), because it applies to different locations in the NPLD and the elevations of these layers change at each location. A detailed description of this work is given in [11] and [12].

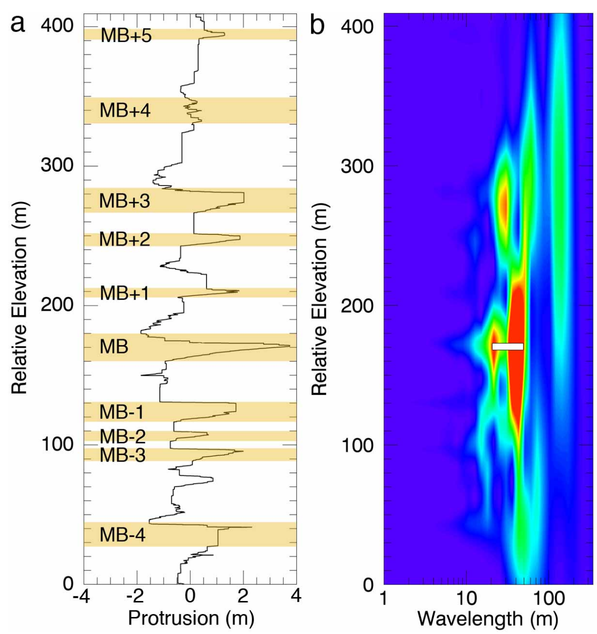


**Fig. 2.** (a) Protrusion-based stratigraphic column that results from the correlation of the stratigraphic signals of sites N0,N1,N6,N8,N10,N15 of fig. 1a. (b) Wavelet spectrum of fig. 2a. The white bar indicates a ratio of ~2.5. Warm colors indicate higher power.

*Wavelet Analysis*

To search for periodic signals in the stratigraphic profile we use wavelet analysis, following the work of Perron and Huybers [6]. This technique is especially well suited for our work because it transforms a periodic 1D time/depth-varying signal into a 2D time/depth-frequency image of spectral power [13], and in doing so allows for the identification of changes in the periodicity with depth. This is done by calculating the wavelet transform through the convolution of the signal with a wavelet function. The wavelet power spectrum (fig. 2b, 3b) is the square of the real portion of the transform, and it is used to determine the dominant periodicities.

There are many types of wavelet functions, each suited for a different type of signal analysis. We use the Morlet wavelet (a sine wave modulated by a Gaussian) due to its higher resolution in frequency space, which is necessary in order to distinguish the dominance of different frequencies along the protrusion profile. A thorough explanation of wavelet analysis is given in [13].

**Preliminary Results and Discussion:** We applied the wavelet transform to our stratigraphic signal shown in fig. 2a, and obtained the power spectrum shown in fig. 2b. We find that the dominant stratigraphic wavelength varies with elevation, and that there is more than one dominant wavelength at any given elevation. The uppermost portion of the profile has a dominant wavelength of ~30 m, with secondary signals at ~60 m and ~150 m. In the middle portion (between 100 and 200 m of relative elevation) the dominant wavelength is ~50 m, with secondary peaks at ~20 m and ~150 m. The lowermost section also has a dominant wavelength of ~50 m. Applying the same procedure to the time-varying peak solar flux at the martian north pole (fig. 3a), results in the power spectrum shown in fig. 3b, which also shows multiple periodicities. The two dominant signals correspond to the cyclic variation of the obliquity (120 kyr), and precession of the argument of perihelion (51 kyr).

The ratio between the most dominant wavelengths in the middle of the stratigraphic profile (~20 m and ~50 m) is ~2.5, and the ratio of dominant signals in the insolation history is ~2.35 (white bars in fig. 2b and 3b). This suggests that the ~20 m and ~50 m signals present in the stratigraphy can be interpreted as climate signals due to the precession of the argument of perihelion and the variation of the obliquity, respectively. Assuming that each of these sequences is deposited in a single cycle of 51 kyr and 120 kyr, this would imply an average accumulation rate for the NPLD of 0.4 mm/yr, roughly consistent with prior estimates [4,5,14].

An important advantage of our approach is that the stratigraphic column we analyze is valid for a large area of the NPLD, and not just for one location. The detection of these signals in the stratigraphy can feed accumulation models and result in more accurate dating of the NPLD, as well as a comprehensive description of the depositional history of the deposits, that is intimately tied to climate change on Mars.

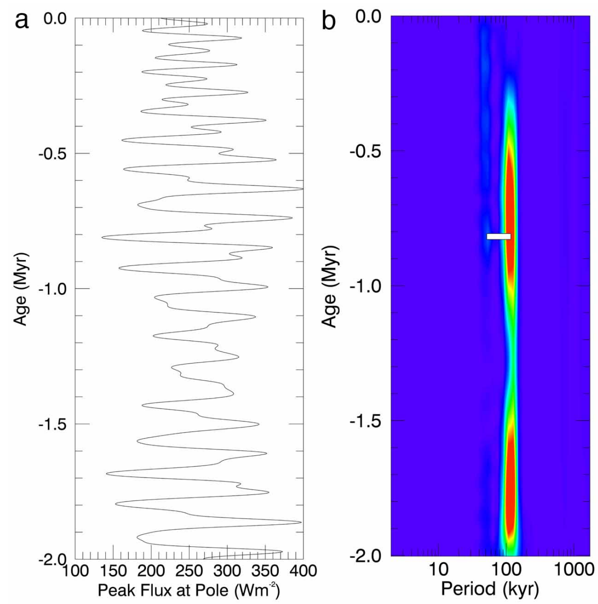


**Fig. 3.** (a) Peak insolation at the martian north pole for the past 2 Myr. (b) Wavelet spectrum of the insolation signal in fig. 3a. The white bar indicates a ratio of ~2.35. Warm colors indicate higher power.

**Future Work:** We will further analyze the implications of our results, and explore the statistical significance of the wavelet analysis following [13], using a Monte Carlo procedure. We will apply the same wavelet transform to random signals that are statistically similar to our protrusion profile, and test the null hypothesis that such a random signal has an equal chance as the data of obtaining a result that is similarly related to the wavelet spectrum of the insolation signal.

**References:** [1] Cutts JGR 78 (1973) [2] Tanaka, et al., Icarus 196 (2008) [3] Phillips et al., Science 320 (2008) [4] Laskar et al., Nature 419 (2002) [5] Milkovich and Head, JGR 110 (2005) [6] Perron and Huybers, Geology 37 (2009) [7] Fishbaugh et al., GRL 37 (2010) [8] Limaye et al., JGR 117 (2012) [9] Herkenhoff et al. Science, 317 (2007) [10] Byrne et al., V Mars Polar Sci. Conf. (2011) [11] Becerra et al., submitted to JGR [12] Becerra et al., LPSC Abs. 1325 (2016) [13] Torrence and Compo, Bull. Am. Met. Soc. 79 (1998) [14] Hvidberg et al. Icarus 221 (2012).