

IS THERE AN ORBITAL SIGNAL IN THE POLAR LAYERED DEPOSITS ON MARS? J. Taylor Perron and Peter Huybers, Department of Earth and Planetary Sciences, Harvard University (perron@eps.harvard.edu).

Introduction: The north polar layered deposits (NPLD) on Mars contain alternating light and dark layers that are traceable over horizontal distances of tens to hundreds of kilometers [1,2]. This stratification appears to result from varying relative rates of dust deposition, ice deposition, and ice sublimation [3], but what do these layers tell us about Mars' paleoclimate? First-order unknowns include the climate condition to which each layer corresponds (warmer/cooler/neither) and the time interval over which the entire sequence was deposited. Another unknown is the extent to which layering in the NPLD results from shifts in orbital configuration, with its attendant consequences for the temporal and spatial distribution of insolation, or variability intrinsic to Mars' climate. That is, are the NPLD a record of quasi-periodic orbital variations, or does the stratigraphy reflect climate events that emerged from the coupled dynamics of Mars' surface and atmosphere?

Studies that have brought recent spacecraft data to bear on this question have identified some support for the hypothesis that the NPLD reflect orbital forcing [2,4]. The same is often argued to be the case for paleoclimate records on Earth [5], but it is worth noting that only ~25% of the variability in late Pleistocene glaciation (as recorded in marine $\delta^{18}\text{O}$) is linearly attributable to orbital variations. The extent to which Earth's glacial variability is stochastic or deterministic is a topic that the terrestrial paleoclimate community continues to debate [6]. Mars is subject to larger orbital variations in insolation and appears, at first glance, to present a simpler climate system, but the manner and extent to which layered deposits record shifts in Mars' orbital configuration remains unclear.

To investigate this issue, we used imagery and topography to construct "virtual cores" through the NPLD, and compared power spectra derived from the stratigraphic sequences with the insolation spectrum produced by a model of long-term orbital dynamics [7]. We examined the NPLD spectra for periodic signals as well as for ratios of periods that might constrain the deposition rate. Although some patterns do emerge, it is difficult to identify clear orbital signatures. We consider four hypotheses for why the NPLD spectra do not contain a clear orbital signal: (1) Mars' climate responds nonlinearly to orbital variations; (2) the manner in which Mars' climate is recorded in the NPLD is complex; (3) the orbital influence is trivial; and (4) our image-based reconstruction of the NPLD stratigraphy contains biases.

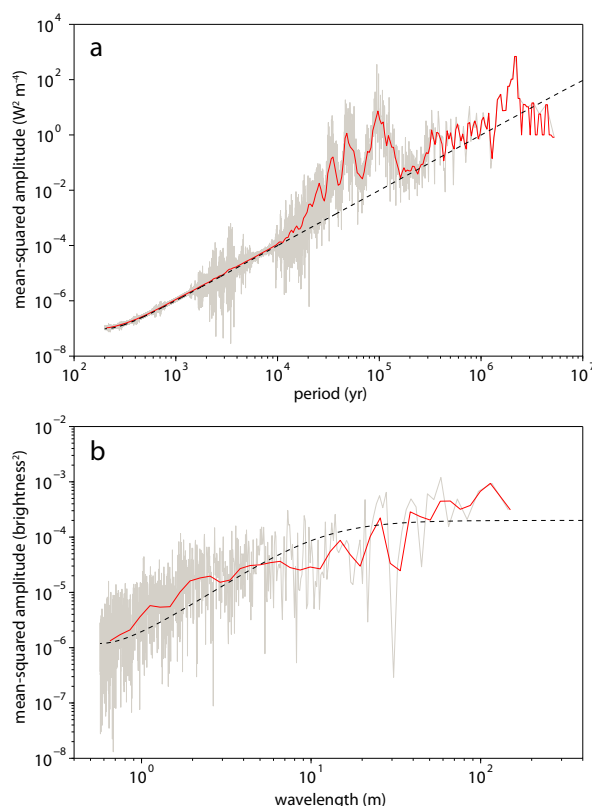


Figure 1. Power spectra corresponding to (a) the last 20 Myr of mean annual insolation at the north pole of Mars, and (b) a depth profile through the upper 500m of the NPLD extracted from MOC image E02-00078 (see Fig. 2). Gray lines are raw spectra, red lines are running means from 300 logarithmically spaced windows, and dashed lines are theoretical spectra for a random process.

Spectral analysis of NPLD stratigraphy:

Methods. Our procedure for reconstructing NPLD stratigraphy is similar to that of [2] and [4]. We processed 30 MOC images traversing NPLD troughs for which the corresponding MOLA profiles were available, and identified the image pixel corresponding to the center of each MOLA shot. Images were then rectified such that elevation varied linearly along the image column corresponding to the MOLA track. Elevations between MOLA shots were interpolated linearly. The resulting series of image pixel values vs. depth was detrended and windowed prior to computing the FFT and power spectrum. We then used the orbital parameters of [7] to produce a time series of the last 20 Myr of mean annual insolation at the north pole of Mars. The power spectrum was computed using the same procedure applied to the image data.

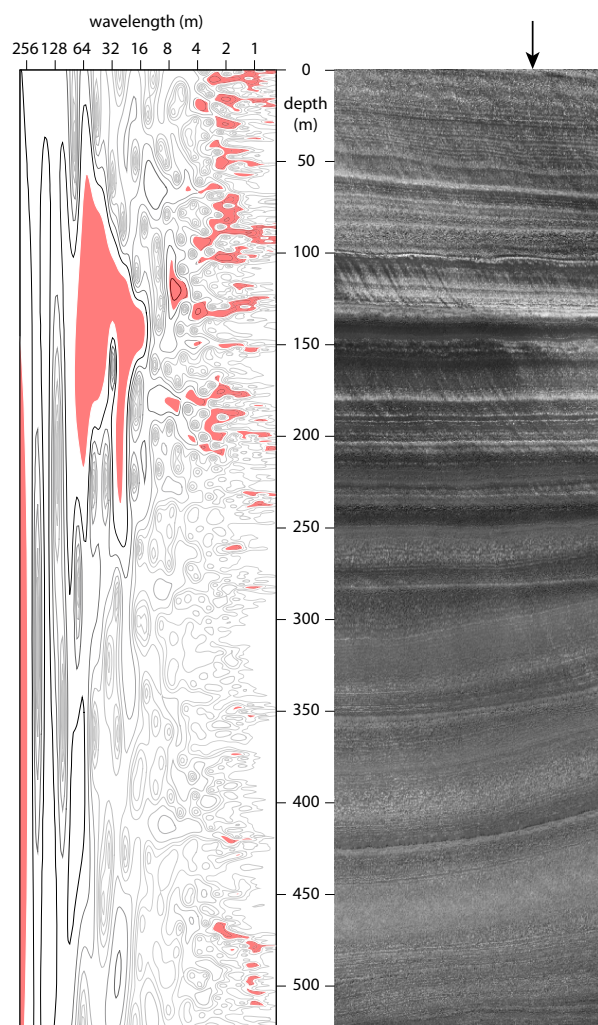


Figure 2. Wavelet spectrum for a vertical profile through MOC image E02-00078, with contours of spectral power (normalized to unit variance) at logarithmic intervals from 2^{-4} to 2^4 . Arrow at top shows the location of the vertical profile, which corresponds to the MOLA ground track. Image has been corrected for topography such that depth increases linearly along the y-axis. Pink highlights show portions of the spectrum that exceed the 95% significance level for a Markov process with the same lag-1 autocorrelation as the data.

Because deformation, unconformities or changes in deposition rate could lead to nonstationary signals (a variable relationship between depth and time), we also performed wavelet transforms on the image data to search for quasi-periodic signals in the NPLD stratigraphy that are localized in depth.

To examine the null hypothesis that the NPLD stratigraphy is the product of a stochastic process, we calculated the theoretical power spectrum for a Markov process with the same lag-1 autocorrelation as each stratigraphic section, an approach commonly used to model red noise [8,9].

Results. As expected, the insolation spectrum (Fig. 1a) contains large deviations from the red noise spectrum at certain periods. The strongest signals overall are the broad peak at ~ 100 kyr due to oscillations in obliquity and eccentricity, and the ~ 2.4 Myr modulation of eccentricity [10,11]. The ~ 50 kyr precession period is also visible, as well as a smaller peak at ~ 35 kyr. Note, however, that the orbital variations are not strictly periodic, making it more challenging to identify any evidence that they influence the stratigraphy.

The power spectra for the NPLD images are more consistent with the red noise spectra than the insolation spectrum (Fig. 1b). The most pronounced deviations, apparent in a number of images, are broad highs in spectral power at wavelengths of ~ 1 -3 m. These signals occur discontinuously in the exposed stratigraphy, so the trend becomes clearer in the wavelet spectra (Fig. 2). In addition to this short-wavelength signal, a less pronounced signal spread over wavelengths of ~ 20 -80 m occurs in portions of some images (Fig. 2). The relationship between this observation and previous reports of repeated stratigraphic units with thicknesses of several tens of meters [2,4] is not yet clear. The tentative observation of quasi-periodic stratigraphic sequences with a ratio of wavelengths comparable to the ratio of the two main periods of the insolation time series ($\sim 24:1$) is interesting. This would imply a deposition rate at the low end of recent estimates [4].

External forcing or internal climate variability?

If the relationship between insolation and the formation of physical stratigraphy is nonlinear [3], it would be surprising to see a simple ratio of periods in the NPLD that map directly to orbital forcings. In many cases, we find that the spectral signature of stratigraphy recovered from the images differs little from that of a stochastic process. Nonetheless, there do appear to be quasi-periodic (but nonstationary) signals in the NPLD with periods ranging from a few meters to nearly 100 meters. Examining the patterns produced by different models for PLD formation [12] could help to determine whether the NPLD contains a decipherable record of insolation changes, or stratigraphy dominated by the internal dynamics of Mars' climate.

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