RHYTHMIC STRATIGRAPHY AT THE ORBITAL MARKER BED AT MOUNT SHARP, GALE CRATER, MARS. K. W. Lewis[1], E. S. Kite[2], C. M. Weitz[3], A. Cowart[3], W. E. Dietrich[4], S. Gupta[5], T. Kubacki[6], E. Rampe[7], J. Schieber[8], S. Simpson[7], L. Thompson[9], M. L. Turner[1], A. Vasavada[10], [1]Johns Hopkins Univ. (klewis@jhu.edu), [2]U. Chicago, [3]Planetary Science Institute, [4]UC Berkeley, [5]Imperial College London, [6]Malin Space Science Systems, [7]NASA Johnson Space Center, [8]Indiana Univ., [9]Univ. of New Brunswick, [10]NASA JPL

Introduction: A distinctive marker bed was first observed from orbital data within the 5 km of stratigraphy of Mount Sharp, even before landing of the Curiosity rover in Gale crater [1]. This singularly dark, erosion resistant bed can be traced around much of Mount Sharp, conforming to surrounding stratigraphy and varying in elevation by more than 1.5 km [2,3]. In 2022 after 10 years of climbing Mount Sharp, Curiosity reached the marker bed, finding it to be a complex stratigraphic interval with multiple distinct sedimentary facies and unusual chemistry [5, 6]. A single bed marked by several cm scale ripples and notably enriched in several metal species appears to be responsible for the erosion resistance observed from orbit. Immediately above this ripple bed, a meter-scale interval of cyclic, planar laminated sedimentary rocks was observed. The patterns observed in this section are unique among Curiosity observations to date, exhibiting two distinct scales of rhythmic laminations. Here, we discuss the observations of the cyclic interval, and potential climate and timing implications arising from these observations.

Observations: Curiosity made observations of the marker bed interval from approximately sols 3640-3698. During this time, the rover traversed ~15 m laterally along this interval, which was additionally well exposed for 10s of meters in either direction. Across this lateral distance, the stratigraphy appears to exhibit three distinct sections. The lowermost interval includes the erosion resistant rippled layer, creating a deep overhang at the bottom of Fig. 1. Above this, two intervals occur, comprised of strikingly rhythmic laminations. The lower of these cyclic units is ~20 cm thick and more erosion resistant, creating subvertical outcrop faces. The upper cyclic interval is up to 1 m thick but less resistant, eroding back into shallow sloping outcrops. The cause of this difference in erosional morphology is not yet clear. As a result, the lower cyclic interval is better exposed and less dusty, while the upper cyclic interval is more obscured by sand and dust (Fig. 1). The lower interval exhibits two separate scales of rhythmic laminations, while the smaller-scale laminae are typically less well expressed in the upper cyclic interval. Neither of the two cyclic units appear to have the strong enrichment in Fe, Mn, and Zn seen in the underlying rippled marker bed [7,8].

During its exploration in this region, Curiosity acquired a number of targeted stereo Mastcam mosaics, along with Navcam context images. In particular, the rover position from sols 3687-3689 was designed to get the higher resolution coverage of the cyclically laminated interval, including with the MAHLI microscopic imager. Two MAHLI mosaics were acquired of the lower cyclic interval at this location, targets Tucuxuma (3688) and Wapixana (3689).

Methodology: To investigate the statistical significance of the rhythmicity that appears to be present within this section, we use Mastcam stereo image and topography data to reconstruct the outcrop

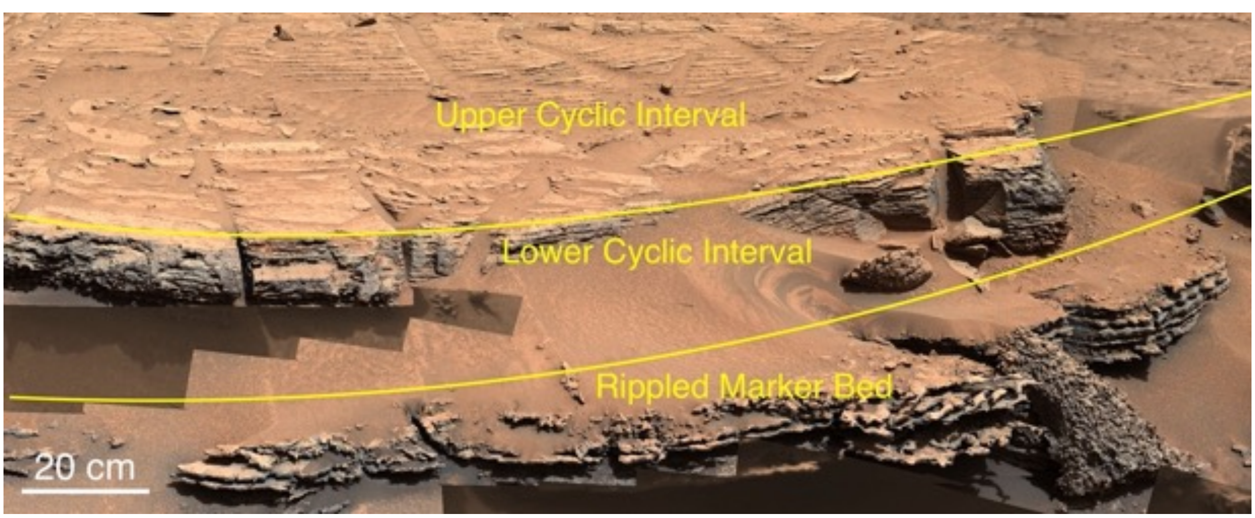

Figure 1: Mastcam mosaic of the marker bed horizon from sol 3688. The stratigraphic interval can be subdivided into three sections, with the upper two exhibiting highly cyclic laminations. Image credit: NASA/JPL/MSSS.

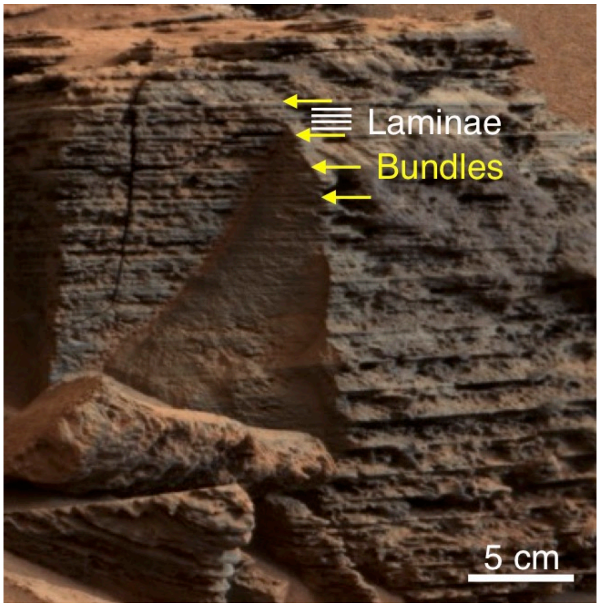

Figure 2: Subframe from a Mastcam mosaic acquired on sol 3640. In this portion of the lower cyclic unit, two discrete scales of cyclic lamination are apparent.

in three dimensions. This allows us to remove the effect of oblique viewing angles, uneven outcrop topography, and tilted layering, all of which can distort the appearance of layering in a 2D image. We first measure the dip of the layering in the outcrop using the procedure of [9]. We then extract color profiles of the outcrop from a Mastcam image, along with its corresponding topographic information from the stereo DEM. We then use the dip of the layering to more accurately calculate the relative stratigraphic position of each pixel within the profile. Averaging across several pixels perpendicular to the outcrop profile can reduce the influence of random shadowing on the outcrop and improve the signal:noise ratio.

Once the stratigraphic profile has been dip-corrected, we can measure thicknesses accurately within the outcrop. We can also apply standard time series tools to the data; here, we use a multitaper Fourier technique to evaluate the statistical significance of the rhythmicity that appears to be present in the outcrop.

Results: At the 3688-3689 rover location, we measure a shallow (5-15 degree) northwestern dip to the layers within blocks of the cyclic units. This does not agree with larger-scale HiRISE topographic measurements of the orbital marker bed and surrounding layers, which suggest a locally northeastern dip to the stratigraphy [2]. The outcrop is heavily fractured, so this may represent secondary tilting of individual blocks rather than a primary depositional orientation. We extracted a color brightness profile from a Mastcam image of the block shown in Figure 2. Multitaper spectral analysis reveals two distinct peaks in power at different spatial scales. The smallest visible laminae have a scale of roughly 2 mm and are bundled into cm-scale packets of 4-5 laminae/bundle. Both spectral peaks rise above the significance level expected for a red noise background.

Implications: The implications of multiple frequencies of cyclic bedding at mm-cm scales are not yet understood. Diurnal, annual, and orbital periods all have a strong influence on the modern Martian climate, but these are orders of magnitude apart in frequency, and orbital periods would imply an extremely low deposition rate (tens of nm/year or less). The 1:4 or 1:5 separation observed within this unit is not well explained by any combination of these frequencies. Speculative interannual influences could include the solar magnetic cycle (currently ~11 Earth years), or a more regular Martian global dust cycle in the past. Tidal interactions with the current configuration of Mars' moons are unlikely to be a strong enough influence to form tidal rhythmites as have been found in ancient rocks on the Earth [10]. Nevertheless, the ability to decode the cyclic patterns recorded at the Mount Sharp marker horizon may provide new insight into the ancient Martian climate.

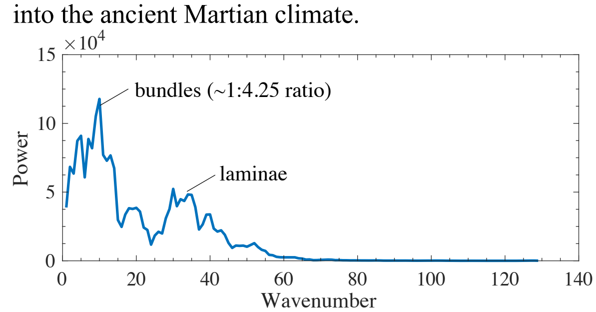

Figure 3: Power spectrum of the lower cyclic interval. Two scales of periodicity are statistically significant, with a period ratio of 1:4-5.

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References: [1] Milliken et al. (2010) *GRL*, doi:10.1029/2009GL041870. [2] Weitz et al. (2022) *JGR*, doi:10.1029/2022JE007211. [3] Kite et al., (2013) *Geology*, doi: 10.1130/G33909.1 [5] Weitz et al, (2023) *LPSC* [6] Gupta et al., (2023) *LPSC.* [7] Thompson et al. (2023), *LPSC*. [8] Gasda et al. (2023), *LPSC*. [9] Turner et al., (2023), in revision. [10] Sonett et al. (1996) *Science* 273(5271).