FINE-SCALE RHYTHMIC SEDIMENTARY LAYERING AT VERA RUBIN RIDGE, GALE CRATER, MARS: POSSIBLE TIDAL FORCING ON ANCIENT MARS. P. Das¹, A. Basu Sarbadhikari¹, R. Sarkar², S. Karunatilakē³, K. S. Edgett⁴, P. P. Paul⁵, J. P. Brothers⁶, S. A. Armstrong⁷
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Introduction: Over the last two decades, the study of Martian sedimentary rocks has enabled detailed interpretations of paleoenvironmental, climatic and astronomical events of Mars [1-7], besides providing a vital archive of the past surface processes. Here we report a quasi-periodic rhythmic variation in millimeter-thick sedimentary banding at Vera Rubin ridge (VRR) of Gale crater, so far, the finest observed cyclic sedimentation on Mars. Such cyclic sedimentary deposit patterns may provide the first glimpse of short-interval orbital forcing of ancient Mars. Absent modern equivalents, this finding is unique as the harmonics of the cyclic layering is dissimilar to any known sedimentary cycles on Mars.

Study Area and Outcrop: VRR is a ~6.5 km long and ~200 m wide, northeast-southwest trending, erosion-resistant ridge which exposes Murray formation rocks. Specifically present are the ~40 m thick Pettegrove Point member and ~15 m thick Jura members units [8, 9]. The studied outcrop, named Jura, is a relatively less dust-coated outcrop such that mm-scale laminae are exposed. It is part of the gray facies [Reference Edgar et al preprint] of the Jura member. The outcrop was investigated in detail by MSL Curiosity between sols 1901 and 1928. The section is characterized by the light and dark toned, millimeter-thick silt/mud to fine sand layers, with randomly distributed millimeter-thick white veins and the molds of tiny crystals of varied sizes scattered through it. At a higher magnification, alternating thick-thin laminae and distinctly preserved dark-toned ‘double mud layers’ have been observed (Fig. 1).

Methodology: The Jura outcrop was first divided into five segments based on visual observation in MSL Curiosity’s MAHLI and Mastcam images. The slope and hence, the scale for each segment (in cm/pixel) were derived from Curiosity’s NAVCAM elevation profile available at the Geosciences Node of NASA’s Planetary Data System (PDS) Analyst’s Notebook for Curiosity (https://an.rsl.wustl.edu/msl/). This was followed by extracting the number of pixels falling on a line orthogonal to each lamina in a GIS environment. The lamina pinched and swelled and so three individuals made three sets of observations each, totaling nine in all, to estimate the statistical variance and associated uncertainty in the readings. On Earth, short-interval, laminated cyclic sedimentary records are commonly found modulated by weak forces such as the neap tides, or they are affected by strong meteorological events, which create difficulties in estimating rhythmicity using direct counting methods. Therefore, a harmonic analysis has been performed using the Fast Fourier Transformation for detailed investigation. The mean and the standard error of the nine readings, for each of the 125 laminae, were used to generate a Gaussian curve with the same mean and standard deviation respectively. From this Gaussian curve, 1000 random readings were extracted to give us a total 1009 readings of laminae thickness in terms of the number of pixels. The number of pixels were then converted to apparent thickness values using the scale values extracted for the respective segments. Apparent thickness values were finally converted into true thicknesses from the slope values for each segment. Then a Fast Fourier Transform (FFT) computation was applied to each of the 1009 set of reading and the average of the outputs is shown in Figure 2. The frequency values were converted to periodicities in terms of the number of laminae/event per bundle.

Result and discussions: The thickness distribution of the total 125 laminae has been represented statistically in a bar chart (Fig. 2a). A cycle containing ~42 laminae was then visually estimated. In the power

Fig. 1. Mastcam image of the studied outcrop Jura is shown in A. The true thickness of the individual lamina has been measured along X-Y marked gray arrow. The distinctly preserved double mud layers observed in B, whose position in A is marked.
Spectral-density plot (Fig. 2b), noteworthy peaks occur at 41.9 laminae, 8.9 laminae, 5.0-4.5 laminae, and 2.1 laminae (Fig. 2). The 41.9 laminae (equivalent to the ~42) has been identified visually in the lamina thickness distribution plot (Fig. 2a), which corresponds to a full-cycle. The 8.9 laminae corresponds to a half-cycle with a prominent sub-cyclic component of 2.1.

The centimeter-thick, quasi-periodic cycles recorded in the outcrop at Jura, which consist of the couplets of silt and mud laminae with clear cycles of 41.9 laminae and a subcyclic component of 2.1 laminae, resembles neither the present-day Martian higher-order orbital cycles nor the solar orbital periodicity (i.e., solar tides or seasonal variation). Moreover, the rhythmic structure cannot be a product of the tidal forces between Mars and its natural satellites, Phobos (7.66 hrs of orbital periods) and Deimos (30.31 hrs of orbital periods), considering their size and periodicity didn’t change. This is because the gravity and angular momentum dynamics involving Phobos and Deimos are likely insufficient to result in a tidal imprint to sedimentation. However, Gale rythmites are reminiscent of terrestrial tidal sedimentary facies. By analogy with the Earth-Moon system, the bundle of 41.9 laminae are the synodic half-month neap-spring-neap cycles, while the sub-cycles of 2.1 laminae can represent the diurnal inequality of a weak ‘semi-diurnal’ to an ‘intermediate (mixed)’ tidal cycles [10, 11]. Therefore, a synodic half-month cycle of at least ~9 s只是 (8.9 lamina in FFT) and a monthly period between 18 and 20 sols can be inferred. Our ongoing research will attempt to interpret this finest-scale rhythmic sedimentary layering in terms of astronomically-forced events on Hesperian Mars.

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