DETECTION OF RHYTHMIC LAYERED DEPOSITS AT ARABIA TERRA, MARS. K. W. Lewis[1], O. Aharonson[1], A. S. McEwen[2], and R. L. Kirk[3], [1]Division of Geological and Planetary Sciences, California Institute of Technology, MC 150-21 Pasadena, CA 91125 (klewis@gps.caltech.edu), [2]University of Arizona Lunar and Planetary Laboratory, 1541 East University Blvd., Tucson, AZ 85721-0063, [3]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001.

Introduction: Sedimentary rocks record a wealth of information about their depositional environment. As such, the extensive sedimentary rock record represents an archive of past climate conditions. For example, the *in situ* observations of the Opportunity rover have constrained the formative climate conditions and role of ground-water at Meridiani Planum [e.g. 1]. In addition to determining the formation mechanisms of various sedimentary deposits, it is necessary to determine the timescales over which they were emplaced, to better understand the potential information recorded.

The light-toned layered deposits of Arabia Terra have been recognized since first imaged at high-resolution by the Mars Orbiter Camera [2, 3]. The morphology of these deposits is further described in [4]. Among these deposits, a few show well exposed outcrops with several hundred meter-long sequences of repeating planar layers. For the first time, we have measured the true stratigraphic thicknesses of these layered deposits, where adequate stereo topographic data from HiRISE are available. These measurements show highly periodic sequences, suggestive of a persistent cyclic depositional process, possibly driven by orbital variations.

Technique: Due to both tectonic tilting of the layers, and erosional sculpting of the surface, it is impossible to measure even relative stratigraphic thicknesses without topographic information. To carry out such measurements, we have constructed digital elevation models (DEM) for several sites in Arabia Terra using stereo images from the High Resolution Imaging Science Experiment (HiRISE) at 25 cm/pixel. These DEMs were processed according to the technique developed by [5] and have a 1 meter horizontal scale, with sub-meter vertical accuracy.

The three dimensional orientation of the layers in a given outcrop are measured according to the procedure outlined in [6], and a mean dip and azimuth are used for the reconstruction. Sections which are faulted or folded were specifically avoided in this study. In plan view, layer positions are identified along a linear traverse from an ortho-rectified image. Finally, these layer positions are projected to a common reference frame, using the orientation measurement [Fig. 1]. The resulting positions represent an accurate stratigraphic column with true layer thicknesses.

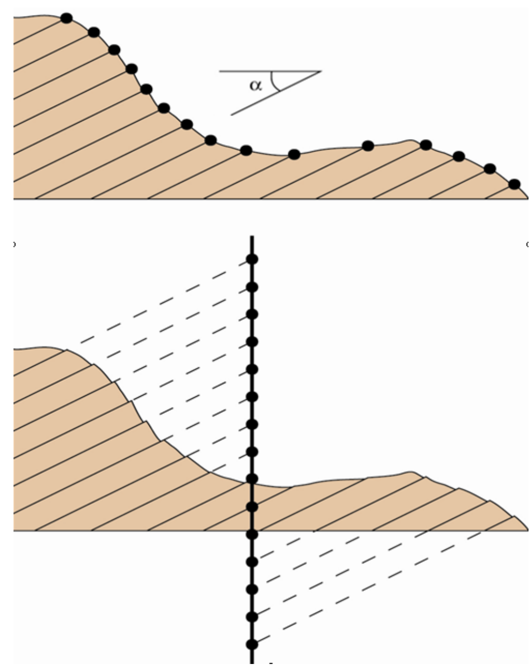

Figure 1: Procedure for reconstructing true stratigraphy of layered deposits. a) First, the three-dimensional orientation of the layers (strike and dip) is measured throughout the section. Next, the positions of individual bedding planes are identified in plan view (black dots). b) Finally, the layer positions are projected to a common reference frame using the measured orientation of the planes. This gives the true stratigraphic thicknesses of the layers.

Observations: Here we summarize the reconstructed stratigraphy of several locations in Arabia Terra. These deposits are found over a wide region, typically as light toned mounds within craters. The layered units typically cover a large fraction, or even the entire floor of a crater, and can expose hundreds of planar layers. Fault and folds are both common in many areas imaged by HiRISE. For these reasons, we have reconstructed the stratigraphy of smaller sections which are intact and not deformed. Measurements of one section at Becquerel crater (shown in Fig. 2), show a consistent layer thickness of 36 meters, with a standard deviation of 9 meters. Other sections show similarly tight clustering about this mean. Such rhythmic bedding has been identified in several locations across Arabia Terra. Layer thicknesses within a crater tend to be highly regular; however, the characteristic layer thickness varies between sites, from a few meters up to a few 10s of meters. The cyclicity observed here is in contrast to many other layered deposits on Mars (e.g., the Valles Marineris wall rock), which more typically show no obvious periodicity.

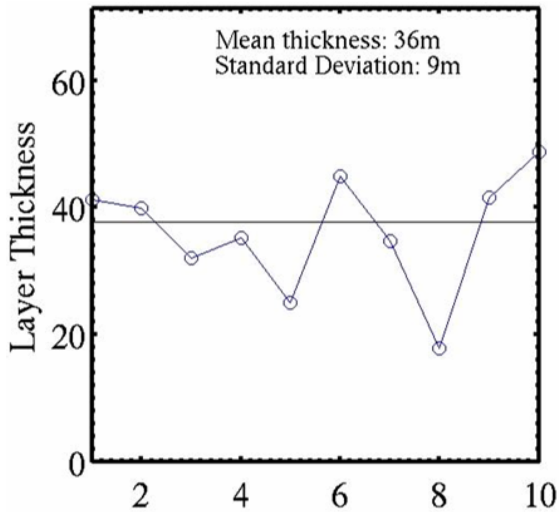

Figure 2: Layer thicknesses for one stratigraphic section in Becquerel crater. Measured values lie within a narrow range about a mean of 36 meters. Several sites in Arabia show such rhythmic layering, although the mean thicknesses vary between locations.

Becquerel. The layered mound within Becquerel crater is unique and particularly useful among the ones studied in that it contains consistent bundling of layers into thicker stratigraphic packages (Fig. 3). We have measured the thicknesses at both scales of layering, and find a remarkable regularity for both. For the thinner layers, we find a mean thickness of 3.5±1.2 meters, while for the bundles, we find a thickness of 36±9 meters. The observation of multiple characteristic layering scales is significant, in that it provides a ratio of periods which may be linked to a specific pair of driving oscillations.

Interpretations: On Earth, cyclicity in the sedimentary rock record is typically found either at diurnal to annual frequencies, or at much longer, orbital, frequencies. On Mars, the present climate has even fewer forcing mechanisms, having neither a thick atmosphere, an ocean, nor a complex cryosphere, each of which can exhibit internal cyclicity. In contrast to sedimentary systems such as that described at Eberswalde crater, the craters studied here do not generally have rims dissected or breached by fluvial channels, nor do they contain obvious deltaic features. Unlike the scenario envisioned for Eberswalde [4], the lack of such features diminishes the likelihood that internally generated (autocyclic) basin-scale oscillations deposited these rhythmic sequences. Given the large volume of the deposits found in Arabia, arranged in layers which are several meters to tens of meters thick, deposition on annual timescales requires unreasonably high deposition rates. Instead, we find deposition at Milankovitch frequencies to be a more likely scenario. In this case, deposition of a ~10 meter thick layer on a time-scale of 10^5 years implies a modest deposition rate of 0.1 mm/year.

The identification of cyclicity in the sedimentary record of Mars also provides information about the depositional mechanism for these layers. Volcanic- or impact-generated debris or airfall are stochastic, and hence do not typically generate rhythmic layering., much less the consistent bundling into larger packages seen at Becquerel. Processes which have a connection to a cyclic forcing function (likely insolation) are favored given the observation of highly regular layering. The most likely candidates would include aeolian and/or fluvio-lacustrine deposition.

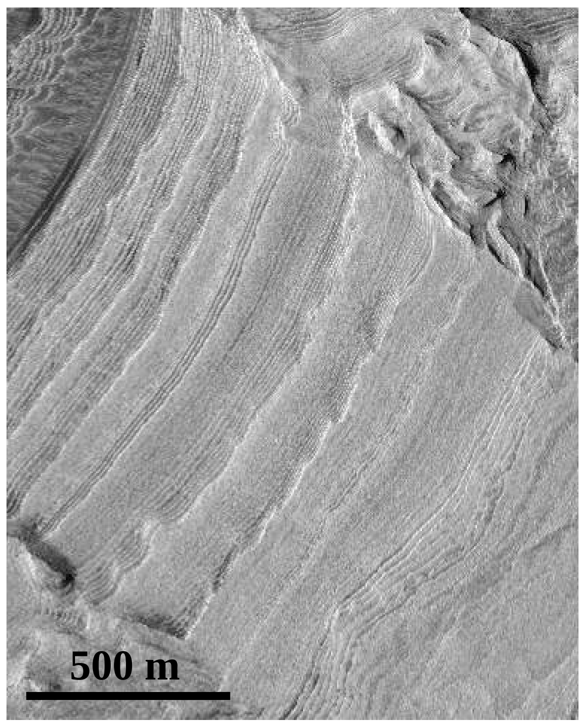

Figure 3: Portion of HiRISE image PSP_1955_2015, in Becquerel crater. This long section shows layering at two distinct scales, with mean thicknesses at roughly 3.5 and 36 meters.

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