Arabia Terra Layered Deposit Stratigraphy from Correlation and Geologic Modeling.

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Introduction: The Arabia Terra region of Mars contains layered deposits inside the interiors of many impact craters [1]. The scientific community has previously determined that the layered deposits were formed by one of a small set of processes, some requiring water and habitable conditions [2, 3, 4]. We have previously investigated the bedding properties and morphology from HiRISE imagery and topography to distinguish two regionally extensive units of the layered deposits [5]. We also concluded that two previously proposed formation mechanisms, groundwater upwelling or airfall deposition (our favored explanation), were consistent with our observations. To further understand the formation of the layered deposits, we now must investigate the geologic record as retained in the geometry of the strata. Challenging our efforts is the lack of complete stratigraphic sections in exposures of the layered deposit.

In this work, we discuss progress towards recovering the complete stratigraphy of the layered deposits in two locations in Arabia Terra and attempts to correlate these strata. Within an individual impact site, multiple outcrops of the layered deposit are typically exposed, that individually and repeatedly record small portions of the complete stratigraphy. Without the exposure of complete sections, these individual sequences need to be integrated together to capture the entire stratigraphy.

Data: We selected two locations of layered deposits studied in [5], Jiji and Sera Craters, both located near 359° and 8.8° North. These sites were selected as the strata are adjacent (within 40-km), and the strata have been previously characterized to be similar in bed thickness and morphology [5]. Selecting nearby and similar strata should provide the most favorable conditions to attempting bedding scale correlations between sites. HiRISE DEMs were produced using the NASA Ames Stereo Pipeline [6] following established procedures [7] as detailed in [5]. Specifically, we used DEMs produced from the following stereo-pairs for Sera and Jiji craters: PSP_001902_1890 & PSP_002047_1890 and ESP_016657_1890 & ESP_01701_1890 respectively.

Methods: From our data, there are two available attributes that can be used to reconstruct the stratigraphy, the positions and orientations of bedding surfaces. As individual outcrops contain a subset of the strata, they sparsely sample the stratigraphy in the volume of the original deposit. The complete stratigraphy can be reconstructed by combining the information from multiple outcrops using the following methodologies on the same underlying data.

Cross-Correlation The first method uses cross-correlations of the dip corrected bed thickness sequences and 3D visualization to recover a longer sequence of stratigraphy. We have established methods of extracting continuous sequences of dip corrected bed thicknesses from individual outcrops of strata by mapping lines along bedding surfaces [5]. Sequences of bed thickness are then cross-correlated with other sequences from immediately adjacent outcrops to establish the offset (aka lag) of the strata from one outcrop relative to another. Once an offset is found, a mean sequence of bed thicknesses is calculated, and additional outcrops are cross-correlated against the new reference mean sequence. The resulting sequence is represented as a stratigraphic column of bed thicknesses ordered by increasing bed index upsection in Figure 1.

Geologic Modeling We also utilized a geologic modeling approach to directly fit a 3D model of strata to the observations and topography [8, 9]. This approach utilizes existing bed position and orientation data used in the prior approach to interpolate a scalar field representing the 3D model of the stratigraphy directly to the data using geostatistical methods [9]. The resulting full 3D model of the stratigraphy enable advanced visualizations that aid correlations of additional sections that were too distant for confident correlation using other methods. In contrast to the cross-correlation method, the geologic modeling approach incorporates additional contextual information to assess correlations of individual outcrops. The final model of the stratigraphy also allows us to remeasure the average bed thicknesses for each bed. Bed thicknesses were characterized by measuring the distances between reconstructed surfaces at the locations of mapped bedding surfaces. This approach ensured that bed thicknesses were sampled at the locations used to produce the model to avoid using interpolated surface values far away from input data sources.

Sera Crater: In Sera Crater, we recovered between 24 and 26 unique beds in the stratigraphy depending on the method used (Figure 1). Prior work found 18 unique couplets in Sera crater [10]. The two methods produced slightly different predictions of bed thickness. Both methods observe a thinning trend upwards from bed index 0 to 7, and both indicated thicker beds at index 9, 13, and 18 relative to beds above and below. The geologic modeling approach found certain beds to be thinner then predicted by the cross-correlation approach, e.g. bed indexes 2, 6, and 15. However, the low number of measurements used for the cross-correlation method re-

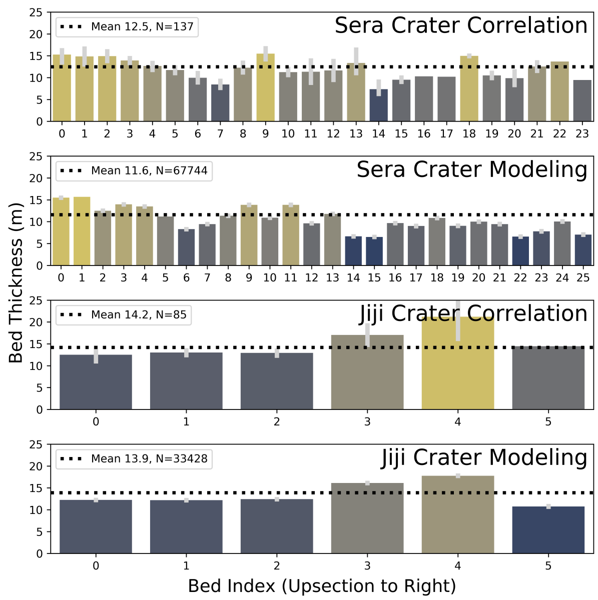

Figure 1: Reconstructed stratigraphic columns for Sera and Jiji Craters ordered by bed index. Bed index starts at 0, the lowest bed in the section, increasing upsection. Bar heights and shading represent the dip corrected bed thickness. Error bars of the bed thickness measurements are reported as small gray lines, beds with too few measurements have no reported error range [11]. Horizontal black dotted lines are the average bed thickness across all measurements in the crater. Mean bed thickness and number of observations reported in figure legends.

sults in larger error bars in comparison to the geologic modeling.

Jiji Crater: In Jiji Crater, despite the use of over 20 different outcrop sequences, only 6 distinct geologic beds were correlated (Figure 1). These beds represent a subset of beds in Jiji Crater that are planar and exposed in small buttes. An additional set of beds with apparent folding were not included in this initial analysis. In the case of Jiji Crater, both methods recovered very similar stratigraphic columns. However, the geologic modeling approach had a much larger sample size allowing higher confidences.

Regional Correlation: Ultimately, we hope to be able to correlate strata between craters like Jiji and Sera at the bedding scale. If strata in both sites were deposited at similar rates and times, the strata should be correlative between both locations. The strata in Jiji and Sera craters have similar properties and occur at a similar range of elevations (-2600 to -2300 m), which could indicate that they are correlative [5]. Using the two stratigraphic columns from figure 1, we used cross-correlation as described above to relate the strata. The combined stratigraphic column and correlation scores are reported in Figure 2. From the cross-correlation, a lag of -3 was determined to best align the strata of Jiji Crater to the strata in Sera Crater. We view the lag of -3 as an unsuccessful correlation due to the small overlap of the strata. The lack of a clear correlation could indicate that the two strata do not correspond.

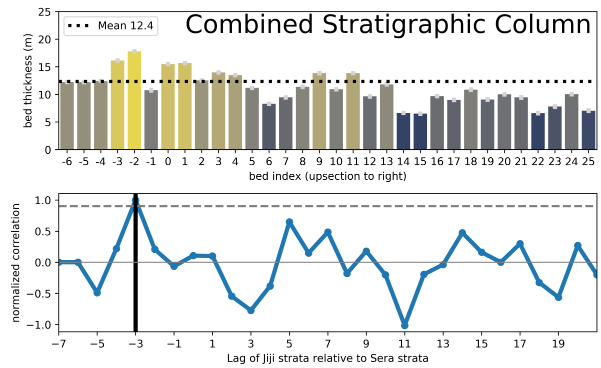

Figure 2: Top: Hypothetical combined stratigraphic column from Jiji and Sera Craters. Bottom: Plot of the normalized cross correlation coefficient, horizontal dashed line is at 0.9, and vertical black line denotes the lag of maximum correlation of strata between the sites.

Future Work: We are working on mapping and correlating additional sections of strata to produce more complete stratigraphic sections at these site and at other locations in Arabia Terra. This will improve the accuracy of the stratigraphic columns and subsequent regional correlations. If the offset calculated here is correct, mapping additional beds down-section in Sera crater could improve confidence in the correlation. Incorporating other lithological information into the stratigraphic column could also contribute to a successful regional correlation.

Conclusions:

1. Stratigraphic columns in two locations are reconstructed with two methods.
2. Geologic modeling produced similar stratigraphic columns to cross-correlation with higher confidence in the bed thickness measurements.
3. We have attempted a preliminary regional correlation of strata at the bedding scale, but find no convincing correlation.
4. The strata could be within the same formation but from disjoint sections of the stratigraphy.

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