Implications of Non-horizontal Stratigraphy at Mount Sharp, Gale Crater, Mars.

K. W. Lewis[1], M. L. Turner[1] and K. M. Stack[2] [1]Johns Hopkins University, Dept. of Earth and Planetary Sciences, Baltimore, MD. [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. (klewis@jhu.edu).

Introduction: Since landing in 2012, the Curiosity rover has ascended roughly 400 meters in elevation from the floor of Gale crater to the lower slopes of Mount Sharp. Of this vertical range, over 300 meters of the rover's traverse has been within the Murray Formation, making up the base of Mount Sharp. The Murray formation is dominantly composed of fine grained sediment below the resolution of the MAHLI instrument (tens of µm), and typically laminated at sub-mm scales. The Murray formation has been interpreted as a lacustrine mudstone [1], potentially resulting from hyperpycnal flows from the crater rim [2].

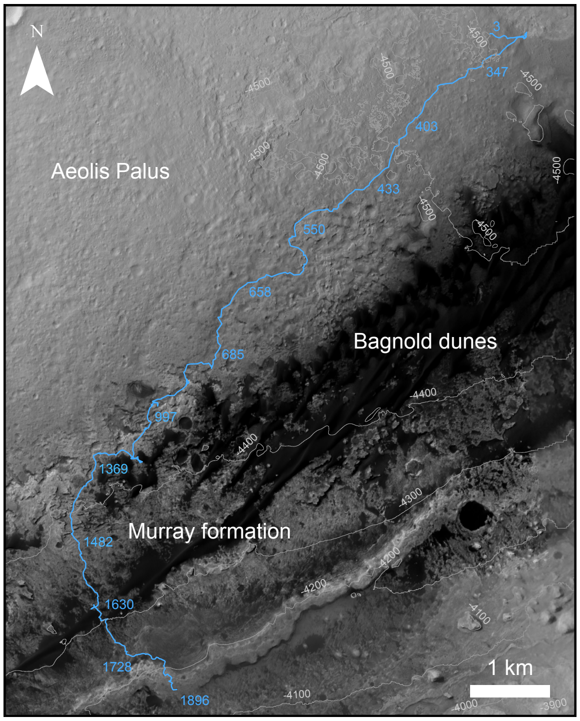

Figure 1: The Curiosity rover traverse through the Murray Formation of Mount Sharp (blue), with elevation contours (gray) to sol 1896.

In contrast, from orbit, [3] suggested a largely aeolian origin for Mount Sharp based on a number of observations, and in particular the radially-outward dipping pattern of layers exposed around its flanks. However, it has been difficult to validate these measurements in situ due to the fine scale of the laminations within the Murray formation, and a paucity of intact outcrops with favorable exposures. However, Curiosity's recent traverse through the Vera Rubin ridge and Glen Torridon areas has provided abundant opportunities for measurement of layer orientations, allowing a comparison to previous orbital measurements, and with possible implications for the depositional origin of lower Mount Sharp.

Methodology: To constrain the regional dip of the stratigraphy in the region of the Vera Rubin ridge, we used a number of independent methods. Our primary technique uses stereo image data from the rover's Mastcam and Navcam cameras to extract topography data along layer exposures (typically at the sub-meter scale), which can than be fit to a planar surface. To bridge the scale gap between orbital and in situ data, we additionally acquired long-baseline Mastcam stereo mosaics of the ridge from two separate rover positions separated by tens of meters. Finally, we were able to take advantage of multiple crossings of specific stratigraphic member boundaries along the traverse to help constrain the regional dip. Specifically, Curiosity crossed the boundary between the Blunts Point and Pettegrove point members, as well as the Pettegrove Point and Jura members, along the traverse at two different locations. Figure 2 shows the combined constraints of these three techniques. Both standard and long-baseline stereo imaging techniques suggest a shallow dip of several degrees to the northwest, with an average of 3.6±0.3° for the normal Mastcam stereo results. The member boundary contacts do not provide a unique solution based only on two crossing locations, but are also consistent with a shallow northwest dip. These measurements are also consistent with previously published results from orbital stereo data [3,4,5].

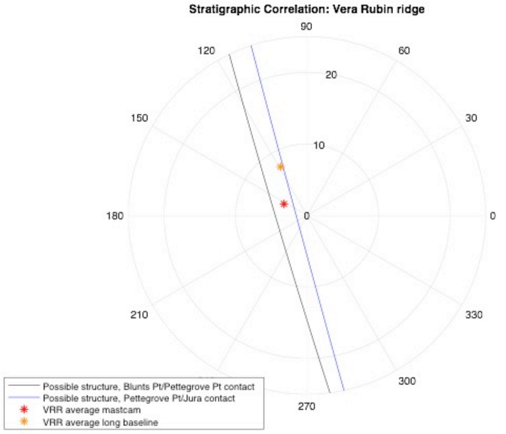

Figure 2: Constraints on the regional dip of the Murray formation, from Mastcam stereo imaging (average dip in red), long baseline Mastcam imaging (average in orange), and from multiple member boundary crossings (lines).

Implications: Given that the modern topographic slope of Mount Sharp along Curiosity's traverse is only ~5 degrees to the northwest, even a shallow downslope dip can have a major impact on the interpreted stratigraphic thickness of the Murray formation. Figure 3 shows the varying thickness of the various members within the Murray formation as a function of layer dip. For our preferred value of 3.6° the total thickness of the Murray formation is reduced by half, while individual members, in particular the Sutton Island and Jura members, are even more substantially reduced in thickness. A more limited true thickness for the stratigraphy traversed thus far at Mount Sharp may help explain, to some extent, the chemical and lithologic homogeneity observed in much of the Murray formation [6].

Because the topographic slope of Mount Sharp is only slightly steeper than the observed dips at Vera Rubin ridge, the projected layers from even the highest portion of Curiosity's traverse are not predicted to extend to the crater rim (Figure 4). Sediment burial and compaction has been proposed as a way to induce a post-depositional tilt within the stratigraphy [1]. However, density estimates from surface gravity measurements suggest the Murray formation retains a high porosity, and has not been significantly compacted [7]. If the observed bedding orientation were primary, it would provide important information for interpreting formative depositional processes.

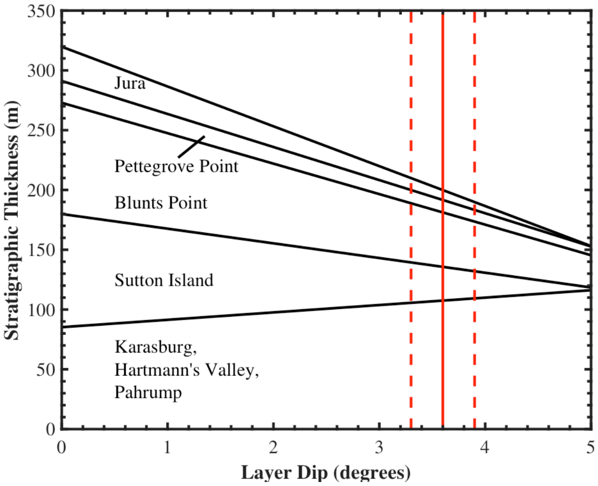

Figure 3: Effect of a regional dip on the interpreted thickness of Murray formation members. A shallow dip to the northwest reduces the thickness of the formation by a factor of two or more, with our estimated dip (and 1-σ error bounds) shown in red.

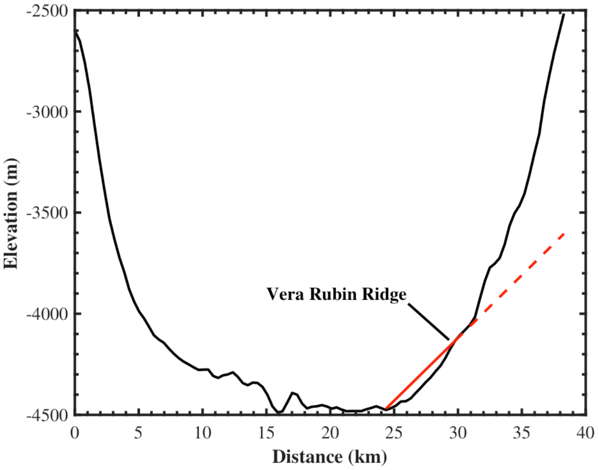

Figure 4: Cross-section perpendicular to strike from the Gale crater rim to Mount Sharp along the Curiosity traverse (black). The projected former extent of the layers at Curiosity's current location to the crater floor, assuming a 3.6° dip, is shown in red.

Future Outlook: Curiosity is now encountering significantly more local-scale topography among several buttes within the Glen Torridon region. These buttes and other upcoming outcrops will provide addional constraints on the regional bedding orientation, which will be necessary to relate widely separated stratigraphic sections analyzed by the rover.

References: [1] Grotzinger, J.P. et al., *Science* 343 (6169). [2] Stack et al., (2018), *Sedimentology* 66 (5) 1768-1802. [3] Kite, E.S. et al., (2013) *Geology* 41 (3), 543-546 [4] Le Deit, L. et al., (2013) *JGR Planets* 118 (12), 2439-2473. [5] Fraeman, A. A. et al., (2013) *Geology* 41 (10) 1103-1106. [6] Yen et al., (2019) AGU Fall Meeting, P33B-05. [7] Lewis, K. W. et al., *Science* 363 (6426), 535-537.