WITH THE NOSE TO THE GROUND – EXPLORING THE PAHRUMP HILLS OUTRCROP WITH MARDI FOR NEW PERSPECTIVES ON THE MUDSTONES OF THE MURRAY FORMATION AT GALE CRATER, MARS.

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Introduction: The Pahrump Hills outcrop is the stratigraphically lowest known exposure of the Murray Formation, a ca. 250 m thick mudstone dominated interval at the base of the Mt. Sharp stratigraphic succession. Curiosity spent 5 months (Fall 2014 to Spring 2015) exploring Pahrump, established the general nature of the stratigraphic succession and confirmed its lacustrine origin [1], and also provided data on the mineralogy and geochemistry of the unit [2, 3].

The Pahrump exposure is a semi-continuous expanse of wind-swept bedrock (ca. 40m by 70m), where better cemented or sandy intervals form resistant escarpments that facilitate stratigraphic subdivision [1]. Because of the better exposure quality of the latter the bulk of the time spent at Pahrump was devoted to their examination. Yet, these target intervals constitute less than 25% of the total exposed stratigraphic thickness. Whereas we learned a lot from the examination of these locations, for understanding the evolution of mudstone successions the vertical sequencing of facies types is an important element for decoding their depositional history [4]. On Earth this is accomplished through systematic continuous description of outcrops and drill cores [4], a luxury not available to us on Mars.

The rover is equipped with the downward facing MARDI camera that was used for descent imaging [5]. The video mode of this camera was used at Pahrump to image the ground the rover was driving over [6]. About 120 m of track were imaged, forming a nearly complete loop over the extent of the outcrop (Fig. 1).

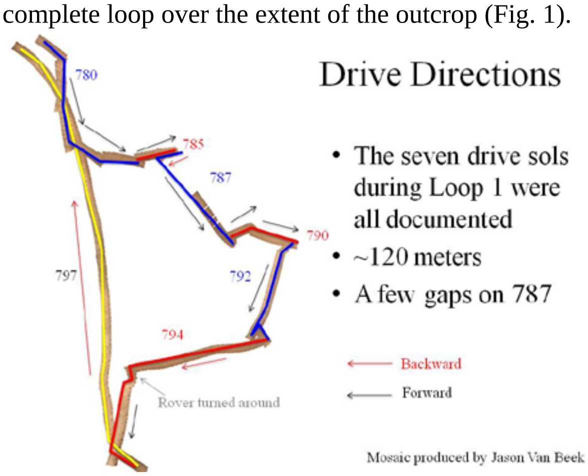

Figure 1: The loop of ground images taken by MARDI at Pahrump.

Because of the excellent exposure at Pahrump, the MARDI images show a nearly continuous record of the outcrop surface and thus allow us to keep track of the changes in mudstone facies as the rover traversed up and down the outcrop. As the elevation of drive end points are known and intermediate elevations can be derived from track overlays on topography, we are in a position to assemble a stratigraphic log and evaluate it for patterns that may give us insights into the depositional history of these rocks.

MARDI Strat Column: Deriving an approximate strat column from outcrop images is common practice for geologists on Earth, with an understanding that such images, even when using a scale, suffer from perspective distortion. MARDI images, due to the fixed position of the camera, do not suffer from that handicap. With known elevation markers along the rover track and a general knowledge of the orientation of bedding, observations can be organized into well resolved lithologic logs. In combination with orbital images and topographic information, the more resistant layers that were studied previously [1] can be traced across the outcrop (Fig. 2).

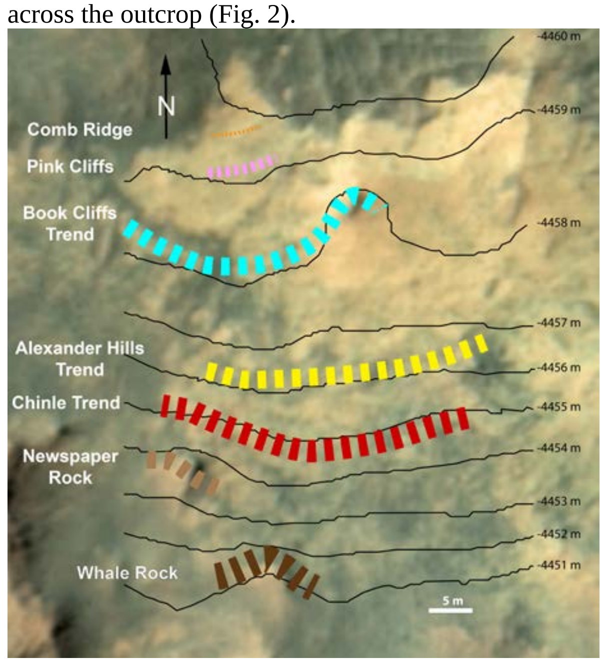

Figure 2: Map of the Pahrump outcrop with contour lines (1 m intervals) and principal stratigraphic markers (white lettering) from prior studies [1]. The dashed trends are more resistant intervals.

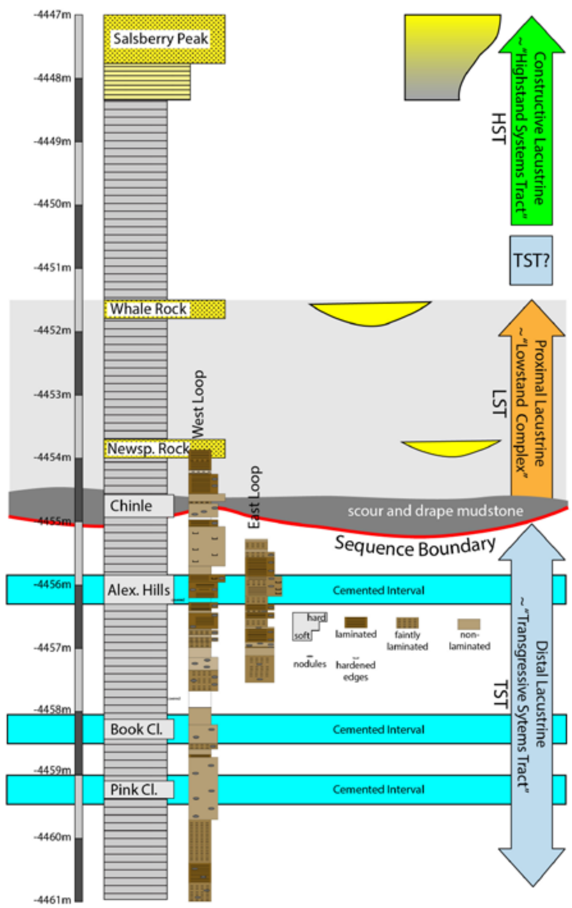

Figure 3: At left, generalized strat section of Pahrump with studied horizons marked (adapted from [1]). To the right of the general section are the results of our examination of the MARDI sidewalk tracks. The long track is the western part of the loop (Sol 797 drive, Fig. 1), and the shorter section (east loop) is the combined Sol 787, 790, and 792 drives. The east loop is not as thick because E-W portions of the track were not included. The right side of the diagram suggests possible sequence stratigraphic interpretations.

The west and east loop sections in Fig. 3 show three types of mudstone facies, superimposed diagenetic features, and perceived hardness of the rocks. We see that harder intervals of these sections line up with better cemented outcrops that have been studied during the Pahrump campaign [1]. This observation and similar lithologic expression between east and west (~30m E-W separation) suggests that these better cemented outcrops are not randomly scattered concretionary bodies, but that instead they follow specific horizons that show enhanced cementation (Fig. 2). On Earth, the latter would imply sediment horizons that reflect slow sediment accumulation [4].

Differences between the east and west loop sections suggest lateral variability in cementation intensity, something that is also observed in terrestrial mudstone successions of all ages. There, cemented intervals stand out through increased erosion resistance and the most intensely cemented portions are recognized as concretions that follow such a horizon and in practical terms enhance its visibility [4]. The thickness of individual layers in these strat sections is calculated from knowledge of their horizontal extent and the average slope between drive endpoints, and can be refined further if the details of topography are additionally considered. Overall, the derived strat sections for the west and east loop show good resemblance (and similar level of detail) to mudstone facies logs obtained on Earth from outcrops or drill core.

Interpretations and Conclusions: Looking at the broader perspective and in the context of the entire 14 meters of strata exposed at Pahrump (Fig. 3), the lower half that is covered by the MARDI tracks could on the basis of fine laminae, potential evaporite crystals in the matrix [7], and cemented-concretionary horizons be interpreted as distal lacustrine strata. These deposits may reflect a time when the lake expanded, periodic variations of sediment supply led to formation of varve-like deposits, and evaporation of surface waters forced precipitation and settling of evporite crystals. In the parlance of modern stratigraphic concepts (Fig. 3) one could equate this with a transgressive systems tract (TST).

A scour surface at the base of the Chinle interval, overlain by undoluse sets of mudstone laminae in a "scour and drape" configuration may actually mark a lake level drop and downcutting into previously deposited muddy strata. Associated channel fill sandstone (medium sand) bodies with x-bedding (Whale Rock, Newspaper Rock; Fig. 3) may reflect transport of sand to the lake interior and be part of a lowstand depositional complex (LST, Fig. 3). Overlying mudstones may record renewed lake level rise, and the coarsening upwards Salsberry Peak sandstone can be interpreted as an infill succession during a lake maximum, possibly equivalent to a highstand systems tract (HST, Fig. 3).

References: [1] Grotzinger, J., et al. (2015) *Science*, 9 October 2015. [2] Thompson, L., et al. (2015) EPSC Abstracts vol. 10, EPSC2015-827. [3] Rampe, E., et al. (2017) EPSL, v. 471, p. 172-185. [4] Lazar et al., (2015) Mudstone Primer [5] Malin, M. et al. (2017) Earth and Space Science, v. 6, p. 506-539. [6] Minitti et al. (2017) 48th LPSC, abstract #2837. [7] Schieber, J. et al. (2015) 46th LPSC, abstract #2153.