

**SEDIMENTOLOGY AND STRATIGRAPHY OF THE PAHRUMP HILLS OUTCROP, LOWER MOUNT SHARP, GALE CRATER, MARS.** K. M. Stack<sup>1</sup>, J. P. Grotzinger<sup>2</sup>, S. Gupta<sup>3</sup>, L. C. Kah<sup>4</sup>, K. W. Lewis<sup>5</sup>, M. J. McBride<sup>6</sup>, M. E. Minitti<sup>7</sup>, D. M. Rubin<sup>8</sup>, J. Schieber<sup>9</sup>, D. Y. Sumner<sup>10</sup>, L. M. Thompson<sup>11</sup>, J. Van Beek<sup>6</sup>, A. R. Vasavada<sup>1</sup>, R. A. Yingst<sup>7</sup>. <sup>1</sup>Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109 (kathryn.m.stack@jpl.nasa.gov), <sup>2</sup>California Institute of Technology, Pasadena, CA, <sup>3</sup>Imperial College, London, UK, <sup>4</sup>University of Tennessee, Knoxville, TN, <sup>5</sup>Johns Hopkins University, Baltimore, MD, <sup>6</sup>Malin Space Science Systems, San Diego, CA, <sup>7</sup>Planetary Science Institute, Tucson, AZ, <sup>8</sup>UC Santa Cruz, Santa Cruz, CA, <sup>9</sup>Indiana University, Bloomington, IN, <sup>10</sup>UC Davis, Davis, CA, <sup>11</sup>University of New Brunswick, Fredericton, NB, Canada.

**Introduction:** In September 2014, the Mars Science Laboratory Curiosity rover arrived at the Pahrump Hills outcrop after an 8 km traverse from Yellowknife Bay. Geologic mapping of high-resolution orbital images from the HiRISE camera suggests that the Pahrump Hills outcrop is Curiosity's first encounter with the Murray formation, the informal designation for strata recognized as lower Mount Sharp (Figure 1). This study presents an overview of the Curiosity rover team's investigation of Pahrump Hills and provides the stratigraphic context and depositional interpretation for sedimentary facies and diagenetic textures observed at this outcrop.

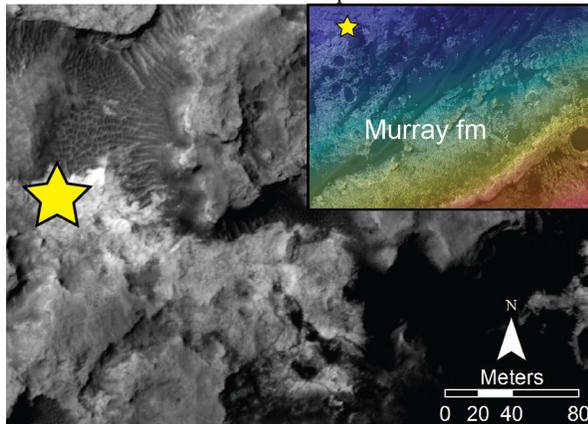


Figure 1. Location of the Pahrump Hills outcrop (yellow star) shown in HiRISE and on a HiRISE digital terrain model (inset).

**The Curiosity Rover Team's Investigation at Pahrump Hills:** After completing sample acquisition and analysis at the Confidence Hills drill site at the base of Pahrump Hills [1], Curiosity began the first of two traverses up the ~12 m thick Pahrump Hills section (Figure 2). During the first traverse, only the remote science instruments (ChemCam, Mastcam, and MARDI) were used to quickly and efficiently characterize the section [2-4]. Several outcrops were then examined during a second traverse using Curiosity's dust removal tool (DRT) and contact science instruments (MAHLI and APXS) [5,6]. Using observations acquired during the two traverses from the Mastcam, MARDI, and MAHLI cameras localized to HiRISE

DTM and Navcam stereo mesh data, a stratigraphic column was constructed for Pahrump Hills using elevations, lithologic, and sedimentary properties (Figure 3).



Figure 2. Main outcrops visited by the Curiosity rover at the Pahrump Hills outcrop displayed on a Mastcam mosaic produced by MSSS. White dots = end of drive or mid-drive stops visited during traverse 1 only, red dots = outcrops examined during traverse 2, blue dot = Confidence Hill drill location.

**Sedimentary Facies at Pahrump Hills:** Five main sedimentary facies were observed at Pahrump Hills (Figure 3):

*Recessively-weathering Massive Mudstone/Siltstone.* The most prevalent facies observed throughout the Pahrump Hills section is a slope-forming, very fine-grained rock that appears massive in Mastcam and MARDI images. Individual in-situ grains are not resolvable in MAHLI images of brushed exposures, which suggests that the grain size of this facies is less than ~50  $\mu\text{m}$ , or 2.5x the maximum MAHLI resolution achieved at a 3.9 cm working distance. Accordingly, this facies is likely composed of clay (<4  $\mu\text{m}$ ) to silt-sized (<30-60  $\mu\text{m}$ ) particles, but in unknown proportions.

*Recessively-weathering Parallel Laminated Mudstone/Siltstone.* Interbedded within the massive mudstone/siltstone facies are very fine-grained intervals exhibiting mm-scale, parallel laminae. Individual laminae are laterally continuous and traceable on the decimeter to meter scale. In the vicinity of Shoemaker, Alexander Hills, and Chinle, the laminae are distinctly rhythmic in appearance. Inclined parallel laminae are observed near Pink Cliffs and Alexander Hills, alt-

though identifying the scale or geometry of potential bedforms is difficult due to outcrop exposure.

*Resistant Laminated to Massive Mudstone/Siltstone.* Resistant mudstone/siltstone intervals are observed at Pink Cliffs, Book Cliffs, Alexander Hills, and Carnivore Canyon. Coarse cm- to mm-scale planar laminae and possible cross-stratification are observed within Book Cliffs, Alexander Hills, and Carnivore Canyon, yet portions of these outcrops appear more massive, likely due to differential secondary cementation. Outcrops of this resistant facies can only be traced laterally for tens of centimeters to several meters.

*Resistant Cross-stratified Siltstones.* Parallel and low-angle, mm-scale cross-laminae are observed in very fine-grained siltstones at the Chinle outcrop. A coarser grain size (predominantly silt) is inferred for this facies due to the presence of low-angle, cross-stratification suggestive of dune-scale bedforms.

*Cross-stratified Sandstone.* At the Whale Rock outcrop in the upper portion of the Pahrump Hills section, a lens of very fine to fine-grained sandstone exhibits dune and ripple-scale cross-stratification. Whale Rock is overlain and underlain by the recessive massive and parallel laminated mudstone/siltstone facies.

**Diagenetic Textures:** Diagenetic textures observed throughout the Pahrump Hills section include: (1) concretions exhibiting aggregate, spherical, and dendritic morphologies [7,8], (2) clusters of crystal laths or pseudomorphs found within the recessive massive and parallel laminated mudstone/siltstone facies [9], (3) light-toned calcium-sulfate filled veins [7,8], (4) parallel-sided, positive-relief ridges of the host rock surrounding veins and cracks, and (5) positive-relief boxwork often associated with light-toned mineralized veins. The concretions, crystal clusters, and parallel-sided, positive relief host rock ridges occur throughout the lower section of Pahrump Hills, but are not observed at or above the Chinle outcrop. The boxwork occurs only in the upper portion of the section beginning at Whale Rock, while the light-toned calcium sulfate veins occur throughout the entire 12 m section.

**Implications:** The systematic but differential distribution of diagenetic textures throughout the Pahrump Hills section suggests multiple episodes of aqueous alteration that were likely influenced by the lithological and rheological properties of the sediment. The very fine grain size of sedimentary rocks within the Pahrump Hills outcrop implies that deposition occurred from suspension for the majority of sediments within the section. The close spatial proximity of the Pahrump outcrop with fluvio- and fluvio-deltaic deposits of Aeolis Palus points to a potential lacustrine interpretation for these sediments, although an eolian or

mixed eolian-lacustrine interpretation is difficult to rule out completely for the very fine-grained facies of the lower Pahrump Hills section. Mud cracks are conspicuously absent throughout the section, although the presence of crystal clusters or crystal pseudomorphs is interpreted by [9] to represent an evaporative environment of deposition. The low-angle cross laminations at Chinle and the dune and ripple cross-stratified facies observed at the Whale Rock outcrop offer compelling evidence for subaqueous deposition in the upper portion of the Pahrump Hills section.

**References:** [1] Cavanagh et al. (2015), *LPS XLVI* this volume, [2] Yingst et al. (2015) *LPS XLVI* this volume, [3] Minitti et al. *LPS XLVI* this volume, (2015), [4] Forni et al. *LPS XLVI* this volume, [5] McBride et al. *LPS XLVI* this volume, [6] Thompson et al. *LPS XLVI* this volume, [7] Nachon et al. (2015) *LPS XLVI* this volume [8] Kah et al. (2015) *LPS XLVI* this volume [9] Schieber et al. (2015) *LPS XLVI* this volume.

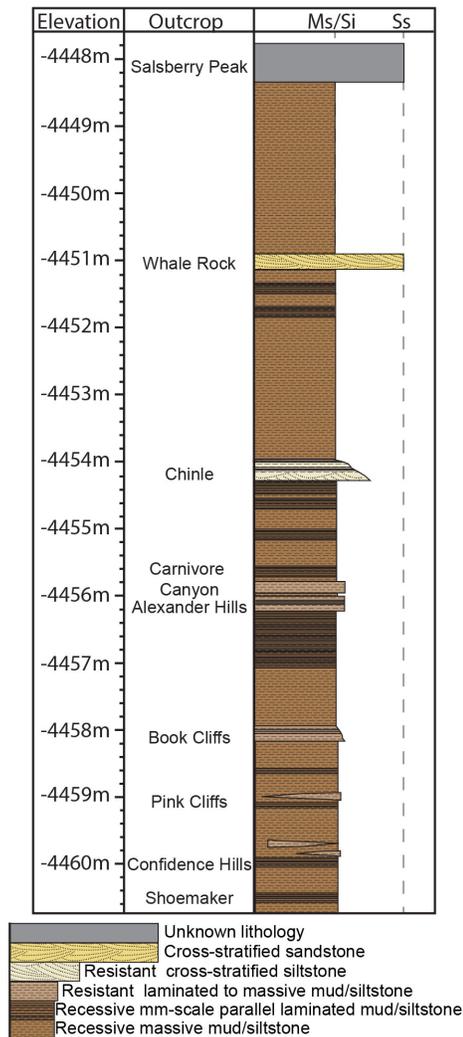


Figure 3. Stratigraphic section for the Pahrump Hills outcrop.