

MARS HAND LENS IMAGER (MAHLI) OBSERVATIONS AT THE PAHRUMP HILLS FIELD SITE, GALE CRATER. M. J. McBride¹ M. E. Minitti² K. M. Stack³ R. A. Yingst² K. S. Edgett¹ W. Goetz⁴ K. E. Herkenhoff⁴ E. Heydari⁵ L. C. Kah⁶ S. K. Rowland⁷ J. Schieber⁸ D. Harker¹ M. R. Kennedy¹ G. M. Krezoski¹ L. Lipkamin¹ B. Nixon¹ J. Van Beek¹ ¹Malin Space Science Systems, San Diego, CA, ²Planetary Science Institute Tucson, AZ ³Jet Propulsion Laboratory Pasadena, CA ⁴Max Planck Institute for Solar System Research Göttingen, Germany ⁵United States Geological Survey, Flagstaff, AZ ⁶Jackson State University, Jackson, MS ⁷University of Tennessee Knoxville, TN ⁸University of Hawai'i at Mānoa, Honolulu, HI ⁹Indiana University, Bloomington, IN.

Introduction: The Mars Science Laboratory (MSL) mission entered a new phase with arrival at the base of Mt. Sharp in September 2014, after traveling over 9 km from the Bradbury Landing site. Curiosity's first science campaign in the Murray Formation began at the Pahrump Hills field site. MSL deployed its full payload on the Confidence Hills drill site (Sols 753-780). Then, the MSL team approached the site as a geologist would, first taking a driving the rover in a loop to survey the area with the remote sensing instruments, Mastcam and ChemCam (Sols 780 – 799). After this first loop, the team chose outcrops to visit during a second loop (ongoing since sol 805 [as of the time of writing]) to conduct contact science utilizing the Dust Removal Tool (DRT), MAHLI and APXS [1, 2]. The team chose to stop at sites named Shoemaker, Pink Cliffs, Book Cliffs, Alexander Hills, Chinle, and Whale Rock (Sols 805– 840+) (Figure 1) [3].

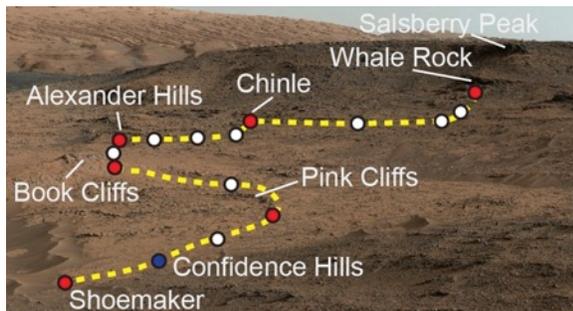


Figure 1: Outline of Pahrump Hills traverses overlaid on a Mastcam mosaic. The red dots represent points where contact science was performed during loop 2 and the blue dot represents the location of a drill campaign. White dots are representative of imaging locations only visited during loop 1. [3]

MAHLI: The Mars Hand Lens Imager (MAHLI) is a macro lens color camera located on the turret of the robotic arm. MAHLI is able to focus on targets at working distances of 2.1 cm to infinity with a maximum resolution of $\sim 14 \mu\text{m}/\text{pixel}$ [4]. Mounted on the turret at the end of Curiosity's robotic arm, MAHLI can be positioned to approach targets from numerous angles. Loop 2 at Pahrump Hills site allowed a different approach to using the MAHLI camera than previously in the mission. The targets were chosen based on the remote sensing data from loop 1. To reduce the possibility of shadowing in the MAHLI images, the direction of outcrop approach and the time of day for science observations were taken into consideration.

Confidence Hills Drill Site (Sols 753-780): The first stop was near the base of Pahrump Hills. Curiosity made its first drill into Mt. Sharp rock in a target named Confidence Hills. Imaging with MAHLI constrained the rock to siltstone or mudstone based on grain size. Resistant diagenetic features surrounded the drill site. MAHLI imaged the site before and after the drilling activity (targets Maturango, Confidence Hills, Paradox) as well as the diagenetic features Mammoth, Moenkopi, and Morrison[5].

Shoemaker (Sols 805-806): After completing the walkabout of Pahrump Hills, the decision was made to return to the base of Pahrump Hills to study the fine laminations of the Shoemaker outcrop. MAHLI imaged two lamination targets; Pelona has fine and evenly spaced laminations, while Ricardo's laminations are coarser (Figure 2). MAHLI images were taken from both a position normal to the surface and an oblique viewing angle looking into the bedding plane during twilight for optimal lighting.



Figure 2: Oblique imaging of target Ricardo at the Shoemaker Outcrop. The target brushed by the DRT revealed both fine and coarse laminations.

Pink Cliffs (Sols 807-810): The MSL team chose to visit Pink Cliffs during loop 2 because the outcrop seemed to be more resistant than the nearby laminated facies and the large number of interesting diagenetic textures. Due to the orientation of the desired targets and the way the rover had to approach the outcrop relative to sun position, the team decided to do all of the MAHLI imaging at night using the white LEDs. This allowed images to be acquired without being in shadow and the lighting could be manipulated using different groups of LEDs. The night imaging is excellent at showing differences in albedo within the rock. Rock target Mojave (Figure 3) shows light toned lozenge

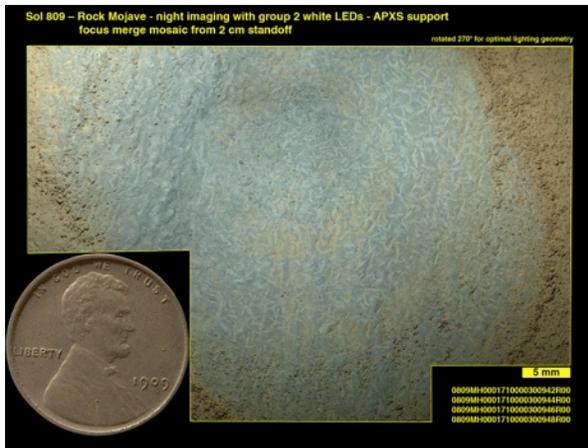


Figure 3: Rock target Mojave was imaged at the Pink Cliffs outcrop. The mosaic acquired at night from a 2 cm standoff, reveals light colored crystal laths in a very fine grained rock.

shaped crystal laths [6]. Other diagenetic features first thought to be hollowed nodules, were identified with MAHLI as diagenetic clusters as in target Potatoe(sic) (Figure 4). Other targets imaged at Pink Cliffs were Rosamead and Pilot Knob Valley.



Figure 4: Focus merge product from 5 cm standoff of rock target Potatoe. The diagenetic clusters are about 1 cm in diameter.

Book Cliffs (Sols 812-816): Book Cliffs was chosen for contact science because Mastcam images revealed a large amount of horizontal planar lamination and possible cross lamination. There was also geochemical data acquired with ChemCam during loop 1 to correlate with APXS observations [2, 7]. Images at Book Cliffs were taken during the day, twilight, and night to capture targets in the best lighting conditions possible. MAHLI images of targets Jail Canyon, Old Dad Mountain, Goblin Valley, and Anaverde revealed rocks with large amount of vugs possibly from the erosive removal of dark particles. Imaging at Book Cliffs of targets Punchbowl, Afton Canyon, and Topanga showed more light toned crystals occasionally with dark toned inclusions.

Alexander Hills (Sols 817-826): Alexander Hills was chosen as a stop on loop 2 because of the chemical anomalies identified by ChemCam on loop 1 [7]. The grain size could not be resolved in targets Puente and Mescal. The rocks were soft enough that the DRT was able to scratch the surface. At Alexander Hills, MAHLI also imaged ChemCam target Cajon.

Chinle (Sols 827-834): Chinle was a standout target from loop 1 because it exhibited parallel and cross-lamination [3]. MAHLI imaged targets Pickhandle, Goldstone, Coachella, and Tropic to study different types of laminations from above the outcrop. A large portion of the outcrop was also imaged at an angle looking into the bedding plane (Figure 5).

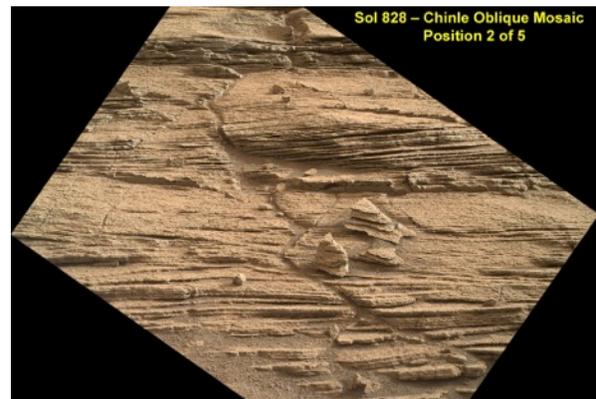


Figure 5: A portion of the oblique mosaic of the Chinle outcrop. There are both parallel and cross laminations visible in the outcrop.

Whale Rock (Sols 837-842+): Due to the constraints on rover positioning, contact science at Whale Rock are being completed on a rock fragment that appears to have fallen off the main outcrop. Observations at Whale Rock reveals a cross-stratified sandstone. MAHLI imaging of the target San Andreas shows a large number of light toned grains.

Conclusions: The Pahrump Hills site in the Murray formation allowed for an in-depth analysis with the MAHLI camera onboard Curiosity. MAHLI's high-resolution images allowed for grain size analysis, up close imaging of laminations and diagenetic features, and placement of the contact science outcrops within the stratigraphy column of Pahrump Hills [3]. Future analysis of MAHLI data will aid in understanding the Pahrump Hills depositional environment.

References: [1] Thompson et al., LPSC 2015 [2] Gellert et al., LPSC 2015 [3] Stack et al., LPSC 2015 [4] Edgett, K.S., et al. (2012), Space Sci. Rev., doi:10.1007/s11214-012-9910-4. [5] Kah et al., LPSC 2015 [6] Schieber et al., LPSC 2015 [7] Milliken et al., LPSC 2015.