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Curiosity's Mars Hand Lens Imager (MAHLI): Sol 0–179 activities, observations, range and scale characterization

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Abstract

During the Curiosity rover's first six months on Mars, images acquired by the Mars Science Laboratory (MSL) Mars Hand Lens Imager (MAHLI) provided critical observations that were used to distinguish a silt/clay-stone from sandstone; interrogate and document the physical properties of an eolian sand deposit and a silt/clay-stone rock in support of sample collection efforts; support robotic arm engineering, tool placement, and wheel position and condition; and contribute to the overall geologic investigation of rocks exposed and only thinly coated with dust in northern Gale crater, Mars.

1. Mars Hand Lens Imager

MAHLI is a 2-megapixel, color camera with a macro lens that can focus on targets at working distances from 2.1 cm to infinity. The camera head is mounted on a rotatable turret at the end of Curiosity's robotic arm. The arm positions the camera for imaging. The investigation centers on stratigraphy, grain-scale texture, structure, mineralogy, and morphology of geologic material. The instrument includes four white light and two ultraviolet (365 nm) LEDs to illuminate targets when warranted. MAHLI onboard data processing includes a focus merge (z-stacking) capability and lossless and lossy data compression options.

2. Activities and observations

Curiosity landed on Sol 0, 6 August 2012 (UTC). Each Sol is one Martian day. Most MAHLI activities during Sols 0–89 focused on instrument, rover, and robotic arm engineering check-outs and investigation of the rover team's first solid sampling site. The activities included (1) interrogation of an eolian sand deposit for suitability to be used for scooping, decontamination of the CHIMRA (Collection and Handling for In-Situ Martian Rock Analysis), and the first solid sample delivery to the Chemistry and Mineralogy (CheMin) and Sample Analysis at Mars (SAM) instruments; (2) documentation of the nature of this sand; (3) verification that samples were delivered to SAM and passed through a 150 µm mesh and a 2 mm funnel throat in the CheMin inlet; (4) development of approaches for subsequent robotic arm positioning of its tools, MAHLI, and the Alpha Particle X-Ray Spectrometer (APXS); and (5) use of MAHLI for range-finding to determine

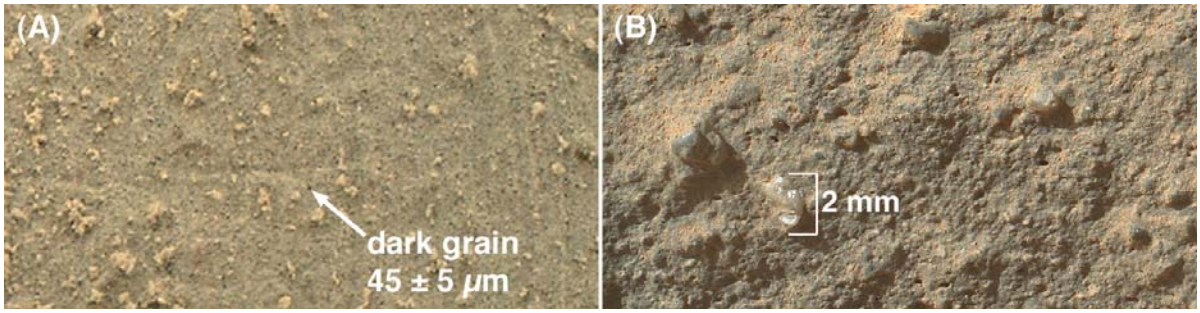

Figure 1: Sedimentary rocks in the Yellowknife Bay field area explored by Curiosity. (A) Portion of a Sol 169 MAHLI focus merge product showing a brushed silt/clay-stone target named Wernecke. The only grains in the rock that are resolved by MAHLI are dark silt particles; the majority of grains are uniformly colored and are the same size or smaller than the dark grains. Loose, unconsolidated, sand-sized clods are evident on the brushed rock surface. (B) Portion of a Sol 132 MAHLI focus merge product showing a sandstone surface with little adhering dust on a target named Gillespie Lake.

locations to position the scoop for sample extraction. The subsequent three months (Sols 90–179) involved (1) interrogation of rocks confirmed by MAHLI (Figure 1) to be sandstones and siltstones (or silt- + clay-stones); (2) further assistance with documenting rover state and conditions (e.g., wheel inspection); (3) imaging support for rock brushing and drill placement; (4) interrogation and documentation of candidate targets to be sampled by Curiosity's drill; and (5) MAHLI's first night-time imaging of a rock target using its UV and white light LEDs.

3. Image range and scale

Throughout the Sol 0–179 period, the MAHLI team continued to refine a technique that uses camera engineering information reported by the instrument (focus motor count) to estimate working distance. Working distance is the range between the front lens element and the subject. Knowledge of working distance also translates into information about the scale of in-focus features in the image. The MSL team uses an additional term to describe the distance to a subject; known as stand-off distance, rover planner distance, or MAHLI tool-frame +x distance, this is measured from a plane defined by the tips of the MAHLI contact sensor probes to the target. Working distance is 1.9 cm greater than the tool-frame +x distance.

The refinements explored by the MAHLI team involved acquiring data after arrival on Mars to (1) confirm the stability of the relationship as measured on Earth and (2) improve, relative to pre-launch data, characterization at distances of 40–200 cm. Equation 1 describes the empirical model we are presently using (subject to further refinement) to relate focus stepper motor count (m) and working distance (w, in cm); this relationship is specific to the MAHLI on Curiosity and has remained stable since final integration of the camera head in August 2008.

$$w = (am^{-1} + b + cm + dm^2 + em^3)^{-1} \quad (1)$$

in which $a = 0.576786$, $b = -11.8479$, $c = 2.80153\times10^{-3}$, $d = -2.266488\times10^{-7}$, $e = 6.26666\times10^{-12}$

Equation 1 is for images acquired by the flight unit MAHLI when its dust cover is open. The dust cover was coated with a film of dust during landing on Sol 0. Thus, cover-closed imaging is rarely performed on Mars. The relationship stated here can be used for working distances between 2.1 and 210 cm. Below 2.1 cm, the camera cannot be focused; above 210 cm, focus is approaching infinity. The camera goes out of focus "beyond" infinity.

Equation 2, describes the relation between working distance (w, in cm) and the width of the area covered by each MAHLI square picture element (p, in µm), assuming the target is in focus and is a plane parallel to the camera's CCD.

$$p = 6.9001 + 3.5201w \quad (2)$$

Depth of field (DOF) contributes to uncertainty in the relation between working distance, motor count, and pixel scale. Depth of field increases with increasing working distance; Table 1 (subject to further refinement) provides examples.

Table 1: Example Depth of Field as Function of Target Distance for Typical MAHLI Images

Working distance (cm)	MAHLI tool-frame +x distance (cm)	Depth of Field (cm)
2.9	1	0.12
6.9	5	0.30
15.2	13.3	1.3
26.9	25	4.4
51.9	50	17
101.9	100	62

Note that, at the minimum working distance of 2.1 cm (MAHLI tool-frame +x of 0.2 cm), each pixel covers an area ~14 µm wide; at 6.9 cm (MAHLI tool-frame +x of 5 cm), each pixel covers an area about 31 µm wide, comparable to the fixed-focus Microscopic Imagers (MI) aboard the Spirit and Opportunity rovers.

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