CLOSING IN ON A MARTIAN MUDSTONE. J. Schieber[1], D. Rubin[2], B. Rossman[1], S. Rowland[3], M. Minitti[4], A. Yingst[5], K. Edgett[6], J. Grotzinger[7], M. Malin[6], and the MSL Science Team, [1]Dept. Geol. Sci, Indiana Univ., 1001 E 10th Str., Bloomington, IN 47405, jschiebe@indiana.edu, [2]UC, Santa Cruz, CA, [3]University of Hawaii at Manoa, Honolulu, HI, [4]Arizona State University, Tempe, AZ, [5]Planetary Science Institute, Tucson, AZ, [6]Malin Space Science Systems, San Diego, CA, [7]California Institute of Technology, Pasadena, CA.

Introduction: The mission objective of Mars Science Lab (MSL)/Curiosity is the identification of habitable environments in Gale Crater. Whereas evidence for surface water was a key aspect of past rover missions, Curiosity's mission is the evaluation of lithologies for criteria of habitability and the preservation potential for traces of ancient life. Mudstones, fine grained sedimentary rocks with a substantial clay component are considered a good bet for preserving ancient organic matter, because they act in that capacity on Earth and are the source from which terrestrial deposits of liquid and gaseous hydrocarbons derive. After landing in August of 2012, rather than driving directly towards Mt. Sharp, the MSL team directed the rover towards a location 500 m to the east (Yellowknife Bay) that from analysis of orbiter images had the potential to contain water lain deposits of an ancient lake [1].

Rover Geology Limitations: Field geologists are accustommed to go up to an outcrop, swing a hammer, then look at the rock through a hand lens, and do all of this in the space of a few minutes. Dooing the same thing with a remote controlled rover takes considerably more time. Usually several days of planning are required and by the time we finally see some close-up pictures of the rock a week may have passed. The other limitation is that once we have driven away from a location, there usually is no turning back. Whatever date we have at that point is final, even if careful analysis of the data suggests that we need to take more pictures or analyses in order to definitely decide between competing hypotheses.

Analyzing Mudstones with Rover Instruments: Mudstones are fine grained rocks with a grain size smaller than 62 µm. The only instrument that can verify whether a given rock qualifies is the arm-attached MAHLI camera with a pixel resolution of ~15 µm at closest approach. Because MAHLI is a limited resource (time consuming to use) as well as being near the limits of its resolution with fine-grained rocks, we looked to alternative ways to detect mudstones by other features, such as the way they are molded by eolian erosion, scraped by the rover wheels, and grooved by the brush and drill tools.

From a Distance: The first hint that we were dealing with a rather soft and fine grained material came from MastCam observations. Differential erosion between Gillespie Lake sandstone (upper) and the Sheepbed member (lower) indicated that the latter had to be much softer than the overlying sandstone.

At the Outcrop: At a distance of ~3 m from the escarpment, Mastcam images showed a distinct textural contrast of the two lithologies (Fig. 3). Whereas the upper unit showed a rough surface studded with resistant granules, the lower unit showed criss-crossing fractures, and between the fractures the rock matrix looked very smooth without resolvable grains.

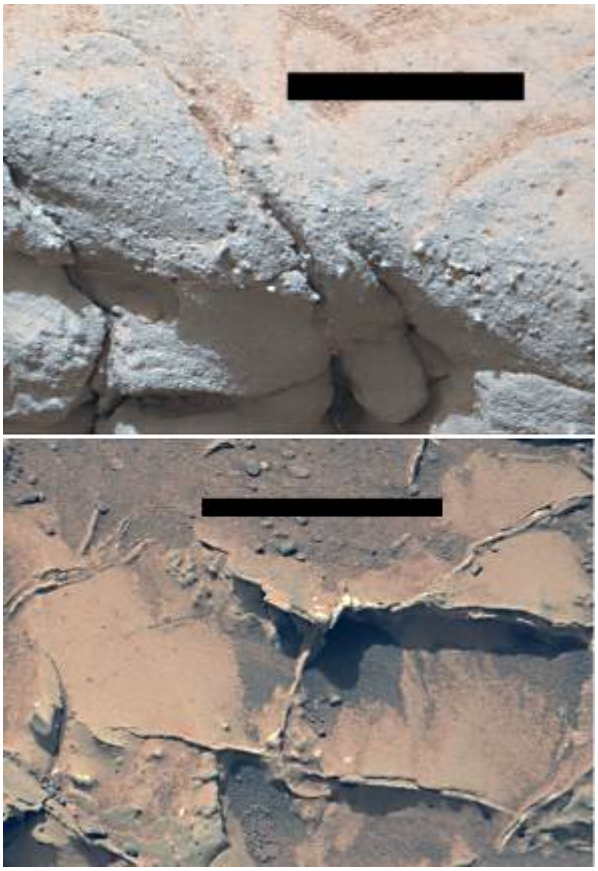

Figure 1: The smooth eroded Sheepbed member (bottom) vs the rough and granular Gillespie Lake member. Scale bar is 5 cm long.

We knew from eolian abrasion experiments on terrestrial mudstones that homogenous mudstones tend to show smooth surfaces, and that this mode of abrasion brings out minute textural details [2]. Thus, the smoothness of the surface was suggestive of a mudstone.

Using the Brush: The rovers brush tool was first deployed on Sol 150 to clean up a likely mudstone surface for later MAHLI imaging. The brush tool grooved the rock surface similar to a steel brush grooving a clay-rich soft mudstone on Earth, confirming that Sheepbed material was similarly soft, and potentially bonded by compacted clay minerals.

Using MAHLI: In MAHLI images from this brushed surface (Ekwir target), the largest visible grains in dust free areas are smaller than 62 microns and the majority of the surface is composed of particles that can not be resolved by MAHLI in closest approach (Fig. 2). They must be substantially smaller than 62 microns, and the rock is therefore a bona fide mudstone by Earth criteria.

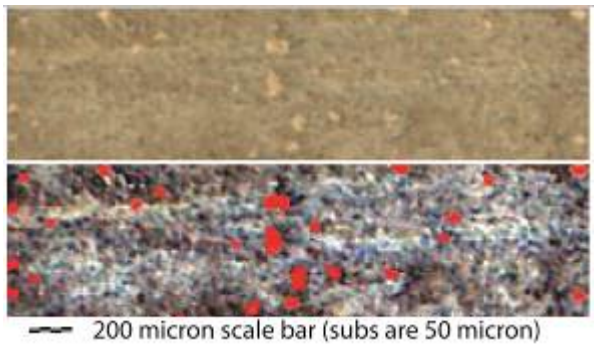

Figure 2: Detail of MAHLI close-up images of the brushed Ekwir target. On top, a white balanced view of an area withy low dust. At bottom, the dust has been marked in red, and the rest of the image was color stretched to enhance grain contrast.

It has been suggested that clay minerals in the Sheepbed mudstones are due to in situ alteration [3]. However, the original particles were most likely also in the mudstone size range, because otherwise we should expect to see altered ghosts of larger original grains (not uncommon in volcaniclastic sandstone on Earth) in the close-up MAHLI images.

Maxing Out MastCam: Additional detail can be gleaned from the many MastCam images that were taken in Yellowknife Bay, because these reveal subtle differences in composition that are accented by differnces in eolian abrasion.

For example, within the Sheepbed member are several preferentially cemented horizons (a few cm to as much as 10 cm thick) that show more erosion resistance and an abundance of small spherical concretions (Fig. 6). By analogy with concretionary beds in terrestrial mudstone, these horizons could suggest intervals with very small sedimentation rates [4].

The Sheepbed member also shows mm-cm thick resistant layers that subdivide the succession into cm-dm thick intervals (Fig. 3, left). These are interpreted as better cemented reworked beds by analogy with terrestrial mudstones.

Experimental eolian abrasion shows that alternating softer and harder beds (Fig. 3, right) produce analogous behavior in alternating gypsum and cement layers. The latter are resistant and get cleaned off smoothly, whereas the former take on a bumpy-irregular appearance. Bumpy abrasion within layers prepared from well mixed gypsum slurry (Fig. 3, right) also suggests that not all the bumps we see in the Sheepbed layers are necessarily concretions. They may instead simply mark minor heterogeneities in the rock matrix.

Our current working hypothesis is that these harder laminae that resulted from reworking by waves or currents in a shallow body of water. Features that strongly resemble current and/or wave ripples support that assessment.

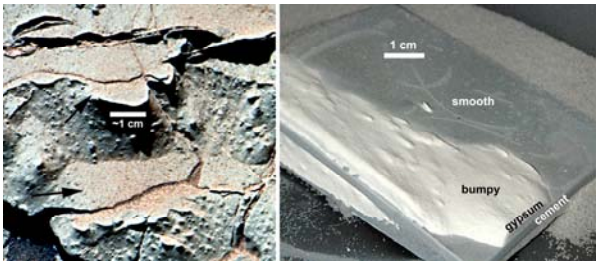

Figure 3: Left, Sheepbed mudstone with prominent hard layers (arrows) and bumpy interlayers. Right, experimental analog where alternating gypsum (soft & bumpy) and cement (hard & smooth) layers produce a comparable effect.

Conclusion: Coarser and more resistant beds associated with ripple features suggest intermittent reworking of fine grained lacustrine deposits by waves and bottom currents in a shallow body of water. Horizons with abundant diagenetic cementation indicate prolonged periodes of very small sedimentation rates or even hiatuses. These observations are consistent with pulses of muddy suspensions that entered a shallow lake [1] and reworking of deposits by intermittent wave and current action. The interpretation of locally ocurring early fractures (raised ridges) as synaeresis cracks [1] is also consistent with this view. The later diagenetic sulfate filled fractures/veins have no direct bearing on the sedimentological interpretation of above noted features.

References: [1] Grotzinger, J., et al. (2013) *Science*, 9 Dec 2013. [2] Rossman, B. et al., (2012) LPSC, abstract 2837. [3] Vaniman et al, 2013 Science, 9 Dec 2013. [4] Potter et al. (2005) *Mud and Mudstones*, Springer.