

DIAGENESIS OF AN ANCIENT LAKESHORE IN GALE CRATER, MARS, FROM MASTCAM MULTI-SPECTRAL IMAGES. J. T. Haber¹, B. Horgan¹, A. A. Fraeman², J. R. Johnson³, S. L. Potter-McIntyre⁴, J. F. Bell III⁵, M. S. Starr⁶, M. S. Rice⁶, N. Mangold⁷, D. Wellington⁵, S. Jacob⁵. ¹Purdue University (haberj@purdue.edu), ²Caltech/Jet Propulsion Lab, ³JHU/Applied Physics Lab, ⁴Southern Illinois University, ⁵Arizona State University, ⁶Western Washington University, ⁷Université Nantes.

Introduction: The Murray formation makes up the base of Mt. Sharp within Gale crater, and is currently being investigated by the Mars Science Laboratory's (MSL) Curiosity rover [1]. The Sutton Island member is a ~98 m thick section of the Murray formation with bedrock exhibiting significant color, textural, and physical variability compared to elsewhere in the Murray formation. The bedrock is characterized by heterolithic mudstone and sandstone, color variations that often cross primary bedding planes, filled fractures resembling desiccation cracks [2], and bedrock sulfate enrichments [3]. Combined, these properties suggest a complex deposition and alteration history in Sutton Island.

Curiosity was only able to collect one drilled sample for quantitative mineralogical analysis in this area, from the base of the Sutton Island member. Thus, the mineralogy of the rest of this member is largely unconstrained [4]. To address this gap and provide insights into the alteration history of this section, we use Mastcam multispectral data to study the mineralogy of Fe-bearing phases within Sutton Island and compare the results to the bedrock properties and terrestrial analogs.

Methods: Mastcam is a multispectral imager composed of two cameras (100/34 mm focal lengths) on the mast of the Curiosity rover. With 12 spectral channels between 445-1013 nm, Mastcam multispectral images can be used to constrain Fe-bearing mineralogy. Images are calibrated to relative reflectance using spectra from a target onboard the rover [5,6]. Here we investigate multispectral images of bedrock in the Sutton Island member (Fig. 1) and compare the spectral properties to the physical properties of the bedrock.

Spectral Diversity: Fig. 1 shows representative Mastcam bedrock spectra of three different spectral classes observed in the Sutton Island member. The first class (blue in Fig. 1) show moderate to strong absorption bands at 860 nm and strong red slopes at short wavelengths, both consistent with fine-grained crystalline red hematite [7]. Consistent with this result, CheMin XRD analysis of the crystalline portion of the only Sutton Island drill sample at Sebina indicated 6.9±0.2 wt.% hematite along with 19±4 wt.% phyllosilicates and 51±25 wt.% amorphous components [8]. Similar spectra are common throughout the Murray [4,9].

The second spectral class (green in Fig. 1) also show strong red slopes at short wavelengths and moderate to strong ferric absorption bands, but the bands are centered at ~900 nm or greater. These spectra are more common in the Sutton Island member than absorption features centered at 860 nm. The ~900+ nm band center

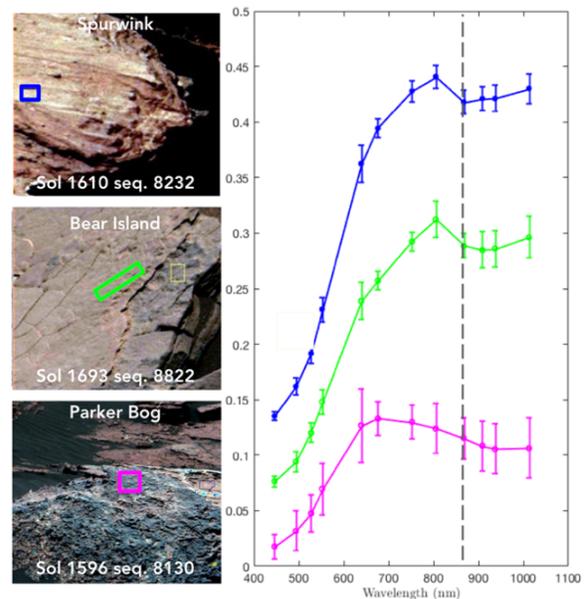


Figure 1: Representative spectra from bedrock with 860nm absorption feature (blue), bedrock with longer wavelength absorption (green), and diagenetic surface (pink) in the Sutton Island member imaged by Mastcam

indicates the presence of iron-bearing minerals other than hematite, including Fe/Mg-smectite (band center ~930 nm), jarosite (~920 nm), akaganeite (~910 nm), or goethite (~920 nm), or a mixture of these phases [10]. Of these minerals, Fe/Mg-smectite has been detected from orbit and CheMin analyses in this region [6,7,8], and akaganeite and jarosite has been detected in some CheMin analyses of the Murray [11].

The third class of spectra (pink in Fig. 1) are relatively flat with peak reflectance near 670 nm. These features suggest the addition of either a more ferrous mineral or coarse-grained iron oxides. These spectra were detected in dark gray features that appear coating bedrock, between layers of bedrock, covering entire outcrops, or as small inclusions within bedrock.

In summary, Mastcam multispectral data reveal disparities between the Sutton Island member and typical Murray formation. While hematite absorption bands are common throughout the Murray [5], they are rare in the bedrock of Sutton Island and sporadic in Blunts Point, the lithostratigraphic member immediately above Sutton Island. Fine-grained red crystalline hematite must be effectively absent in some parts of Sutton Island, otherwise it would dominate all relatively dust-free spectra [7]. Instead, other Fe-bearing phases must be present to generate the longer wavelength band centers.

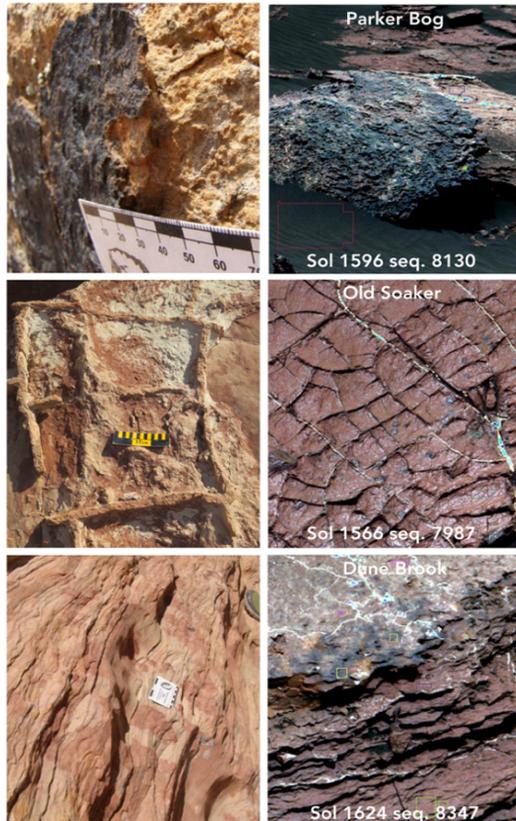


Figure 2: The effects of diagenesis and desiccation can be seen in the Navajo Sandstone (left) and appear similar to the features observed in the Sutton Island member (right).

Depositional Environment: While most of the Murray formation is made up of finely laminated mudstones, which are often deposited at depth within a lake, the heterolithic mudstone and sandstone facies suggests that the Sutton Island member was deposited much closer to the shoreline [12]. Polygonal fractures (middle of Figure 2) are likely desiccation cracks as a result of periodic wetting and drying in this shoreline setting [2], and periods of evaporation could also explain intermittent sulfate enrichments in the bedrock [3].

Evidence for Diagenesis: Sutton Island is also distinctive in terms of color. Bedrock in most of the Murray formation is relatively monotone brown with a reddish tint, while bedrock in Sutton Island varies from brown to a much deeper red hue to a very pale reddish brown or even white color. This transition can be observed within individual outcrops, as shown in the bottom of Figure 2. In addition, the bedrock exhibits abundant dark gray materials which appear in a variety of forms and scales, including coatings, between layers, small inclusions, or covering entire outcrops [13] (Figure 2). These features are rare elsewhere in the Murray. Many of these dark features exhibit different spectral signatures than the surrounding bedrock (pink spectrum, Figure 1). These color variations and dark features are likely due to diagenetic alteration in Sutton Island.

Terrestrial Analogs: Many of these color variations are similar in appearance to rocks altered during early and/or late diagenesis on Earth. Early diagenesis occurs during or after deposition when near surface conditions play a bigger role than groundwater, while burial or late diagenesis occurs during burial and lithification when rocks are under greater temperature and pressure. Concretionary coatings (top of Figure 2) are formed on Earth during late diagenesis where an iron crust fills pore space along a fracture [14]. This is similar to the surface of the target Parker Bog observed on Sol 1596. Uniform red hematite like that observed in the Murray can be (but not always) emplaced by early oxidizing diagenetic fluids [15], and then can be modified at early or late stages. The red/white mottling shown in the bottom of Figure 2 is likely due to mobilization of iron during burial diagenesis, where red pigmentation from fine grained hematite is “bleached”, either by dissolution and removal of iron or local coarsening to gray hematite [16]. Similar mottling was observed in the Sutton Island member, and at larger scales in Vera Rubin ridge [10].

Discussion: In Mastcam spectra, Sutton Island lacks the weak hematite signatures found throughout the Murray and instead displays stronger absorption bands shifted to longer wavelengths. These observations suggest that the Sutton Island member has a distinct mineralogy compared to the rest of the Murray formation, and thus may have experienced both different deposition and alteration histories. This could include deposition in a shallow lakeshore environment and different conditions during multiple episodes of early and late diagenesis. We hypothesize that the spectral properties of Sutton Island are due to additional Fe/Mg-smectites in the bedrock, perhaps due to enhanced precipitation of smectites via weathering along the lakeshore. Additional smectites could also have inhibited diagenetic fluid flow relative to the rest of the Murray. Early diagenetic alteration could be related to the lake environment; e.g., a redox gradient within the lake [17, 18] or local environments along the shoreline. Dark patches and concretions could be due to early or late diagenesis, while late diagenesis is likely responsible for iron mobilization to form dark fracture fills. Together, this suggests a long-lived and variable history of fluid chemistry.

References: [1] Siebach et al. (2019) *LPSC* 1479 [2] Stein et al. (2018) *Geol.* 46 6 [3] Rapin et al. (2019) *Nature Geo.* 12 [4] Rampe et al. (2019) *Mars* 9 6054 [5] Bell et al. (2017) *Earth & Space Sci.* 4 396 [6] Wellington et al. (2017) *Am Min.* 102 1202 [7] Morris et al. (1989) *JGR* 94 2760 [8] Bristow et al. (2018) *Science* 4 eaar3330 [9] Jacob et al. this conference [10] Horgan et al. (2019) *LPSC* 1424. [11] Morris et al. (2019) *LPSC* 1127 [12] Fedo et al. (2019) *Mars* 9 6308 [13] Sun et al. (2019) *Icarus* 321 866 [14] Chan et al. (2000) *AAPG Bulletin* 84 [15] Eichhubl et al. (2004) *GSA Bull* 116 9/10 [16] Parry & Chan. (2004) *AAPG Bulletin* 88 2 [17] Hurowitz et al. (2017) *Science* 356 eaah6849 [18] Potter-McIntyre et al. (2014) *JSR* 84 875-892