

VIS/NIR SPECTRAL DIFFERENCES OF MATERIALS WITHIN GALE CRATER, MARS: PARAMETERIZATION OF MSL/MASTCAM MULTISPECTRAL OBSERVATIONS. D. F. Wellington (dfwellin@asu.edu)¹, J. F. Bell III¹, J. R. Johnson², M. S. Rice³, A. A. Fraeman⁴, and B. Horgan⁵. ¹Arizona State University, ²Johns Hopkins University/APL, ³Western Washington University, ⁴NASA/JPL, ⁵Purdue University.

Instrument and Dataset Description: The Mastcam cameras aboard the Mars Science Laboratory Curiosity rover are capable of acquiring images of the surface in fourteen different filters that span the wavelength range from 400-1100 nm [1,2]. The combination of narrow-band filter positions and broadband Bayer imaging provide twelve unique band center wavelengths from which, for a full-filter observation, 12-point spectra can be derived for pixel regions within the image. Pre-flight and in-flight observations, including near-in-time imaging of the on-board calibration target, allow the images to be accurately calibrated to reflectance (I/F) [3,4]. The rover has acquired more than 200 full-filter (i.e., using all but the solar filters) multispectral observations of surface targets. Over the course of the rover's traverse across the crater floor and lowermost units of Mt. Sharp, a large variety of spectral classes of materials have been observed by the cameras (e.g., [5,6]). Understanding the extent of the spectral variations, their spatial distribution, and the underlying the compositional differences will aid in understanding the geologic history of Gale Crater.

Motivation and Methodology: The Mastcam camera CCD detectors each have an active imaging area of 1600 by 1200 pixels [1,2,4], although observations are often subframed to 1344 by 1200 to exclude corner vignetting. Each image, therefore, will contain over 1.6 million pixels. Individual regions of an image cube can be investigated to derive an average spectrum of a target of interest (as done by [6], e.g.); however, it is often desirable to define spectral parameters that will allow quick identification of pixel regions with particular spectral features. This may serve to map the distribution of a particular spectral feature within an image, to find further examples in other observations, or to search for features that are anticipated on the basis of orbital spectral mapping. Spectral parameters may be band ratios, spectral slopes, band depths, or other properties of the reflectance spectrum, or combinations that may identify a particular spectral class of material within the dataset. For tactical purposes in an ongoing mission such as MSL, spectral parameters may be used to quickly identify a region within downlinked images for follow-up observations, or to design observations to search for or map a region exhibiting a particular spectral signature using a minimum number of filters to reduce data usage.



Figure 1: Top: M-34 color image (cropped) from sol 1032 (1032ML0045100020305553E01). Bottom: Relative 751-867 nm (L3-L5) slope values of the same region. The small rock slabs in the center have unusually strong negative slope between these wavelengths that show up as dark in this spectral parameter.

We summarize several parameters that have proved useful in identifying surfaces exhibiting particular spectral features within the MSL/Mastcam multispectral dataset. Many of the filter band centers mentioned in the text below refer to M-34 (i.e., the left camera) filter positions. The left camera has a wider angular field of view, making it more apt for surveying for spectral features except in cases where the target of interest is small or distant.

Results: Mastcam's filter set is well-suited to identify differences in iron mineralogy of bedrock units, float rocks, or other materials [3,6]. Minimally-altered, basaltically-derived sedimentary units possess low reflectance values and commonly exhibit a weak absorption feature near 1- μm due to primary Fe^{2+} -bearing minerals such as pyroxenes and olivines. Undisturbed martian surfaces are dust-coated to varying degrees, and thus often have a strongly reddish spectrum that can mask visible wavelength features and subdue near-infrared absorptions. Nevertheless, within Gale Crater the dust is commonly thin enough on many surfaces that spectral features can be identified even on undisturbed dusty surfaces.

Identifying localized spectral features of unusual materials in surrounding bedrock: ferric sulfate at

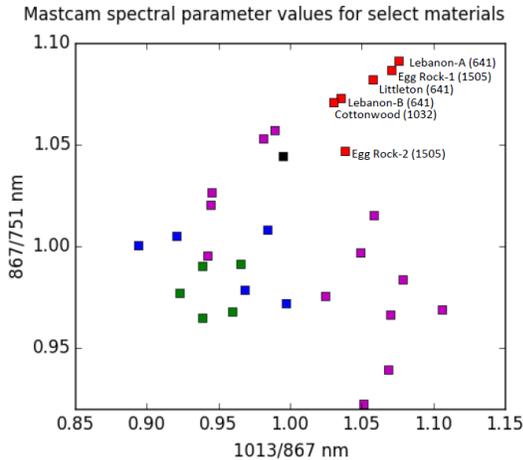


Figure 2: Spectral ratio values of suspected meteorites (red squares) cluster above and/or to the right of other points (labels are target names, sol # in parentheses). Other colors are Bradbury group materials (blue), Stimson (green), Murray (magenta), and a dust-covered surface (one point, black).

Marias Pass. Multispectral observations at several locations in lower Mt. Sharp units revealed the presence of small-scale spectral variability. Several rock surfaces at Marias Pass possess strong near-infrared absorption features centered shortward of 1- μm , consistent with a ferric sulfate. Unlike the surrounding bedrock, this material has a strongly negative slope between M-34 filters L3 and L5 (751 and 867 nm). A grayscale image showing the strength of this parameter (Figure 1) shows that these two filters are sufficient to uniquely identify the unusual material in the context of the surrounding rock slabs, sand, and dust cover. A survey conducted using those two filters revealed that this strong spectral feature is rarely expressed in the surrounding bedrock to this degree or else is restricted to spatially small regions.

Mapping a spectral signature observed from orbit: hematite-bearing layers of the mound. Understanding the spatial and stratigraphic extent of hematite-rich layers identified by CRISM observations of the lower mound has implications for the aqueous history of these units [7,8]. Hematite possesses several absorption features within the spectral range of the filter set, but the 860 nm absorption band is less sensitive to dust cover than shorter-wavelength features. In spectral parameters, hematite-enriched bedrock can generally be found by a stronger 867 nm band depth, or by using two filters to measure the strength of the long-wavelength upturn between 867 and 1013 nm (M-34) or 908/937 and 1013 nm (M-100). This feature is characteristic of the “Hematite Ridge” observed from orbit; however, some drill targets measured to contain elevated hematite by CheMin (e.g., [9]) do not exhibit these near-infrared properties, perhaps reflecting variations in hematite grain size distribution between locations.

Searching for a spectral class within the dataset: iron meteorites. Reflectance spectra of iron meteorites are well-known from terrestrial samples and are characterized by a gradual increase in reflectance throughout the Mastcam spectral range [10]. Several likely meteorite fragments have been identified along Curiosity’s traverse on the basis of their distinctive morphology [11,12]; however, in instances where such a morphology is not apparent, these rocks can sometimes be easily recognized in multispectral observations. Most martian spectra have 1013/867 nm ratios less than or close to 1.0 (i.e., either a flat spectrum or a spectral downturn at long wavelengths); the exceptions are spectra from the hematite-bearing portion of the Murray Formation. The latter, however, commonly have a downturn between the 751 and 867 nm filters (due to a hematite absorption), in contrast to the positive 751-867 nm slope for low-dust surfaces of an iron meteorite. The Cottonwood target (small float rock) from sol 1032 at Marias Pass is an example of such a find by Mastcam multispectral. Near-infrared spectral parameters of this and other putative iron meteorites occupy one portion of the plot shown in Figure 2.

Summary and Future Work: These examples demonstrate the utility of the multispectral capability of the Mastcam instrument suite to identify and map spectral signatures of bedrock, float, and small-scale alteration features along the Curiosity rover’s traverse up the slopes of Mt. Sharp. Identifying parameters that uniquely define a spectral class of material for the complete spectral diversity observed during the mission will provide the means to map the occurrence of these materials along the entirety of the traverse, and in doing so, to better understand the changing mineralogical environments encountered by the rover as it investigates the environment of Gale Crater. From a tactical perspective for the ongoing mission, as well as future missions with similar multispectral imaging systems, understanding the Mastcam parameters that allow for the rapid identification of specific mineral signatures can aid in quick assessment of downlinked data and tactical planning, with the goal to enhance science return and operational efficiency within data volume constraints.

References: [1] Malin et al. (2010) *41st LPSC*, 1123. [2] Bell et al. (2012) *43rd LPSC*, 2541. [3] Bell et al. (2013) *44th LPSC*, 1417. [4] Bell et al. (2016) *Earth & Sp. Sci.*, submitted. [5] Wellington et al. (2014) *LPI Contrib. #1791*, 1454. [6] Wellington et al. (2017) *Am. Min.*, in press. [7] Fraeman et al. (2013) *Geology* *41*, 1103. [8] Fraeman et al., this conference. [9] Cavanaugh et al. (2015) *46th LPSC*, 2735. [10] Gaffey (1976) *JGR* *81*, 905. [11] Johnson et al. (2014) *AGU Fall Mtg.*, #P51E-3989. [12] Meslin et al., this conference.