DETECTING HIGH MANGANESE PHASES IN CURIOSITY MASTCAM MULTISPECTRAL IMAGES AND CHEMCAM PASSIVE VISIBLE TO NEAR INFRARED SPECTRA.

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Introduction: The Mars Science Laboratory (MSL) *Curiosity* rover ChemCam instrument has detected manganese in greater abundances than previously identified on Mars, indicating the presence of a manganese-rich phase [1, 2, 3]. Mn oxides suggest the martian surface may have been more highly oxidizing than previously recognized and the presence of manganese-rich phases provides an additional indicator of habitable aqueous environments [1, 2]. On Earth, Mn oxides can be concentrated on rock surfaces throughout an outcrop. Remote detection of elevated Mn with *Curiosity*, however, is limited to the relatively narrow spot size of the ChemCam laser. Mastcam may make an ideal scouting tool for these types of surfaces, particularly if the visible-to-near-infrared spectral properties of Mn oxides are unique. Given the importance of Mn-rich phases for understanding past habitability, and the high abundances of Mn identified with ChemCam LIBS (Laser Induced Breakdown Spectroscopy), we compare the visible-to-near-infrared passive spectra acquired with *Curiosity's* ChemCam and Mastcam instruments to laboratory spectra of samples with known Mn-abundance. We also investigate the utility of using wide-angle Mastcam multispectral imaging surveys to identify areas for subsequent detailed analysis with ChemCam.

The Mastcam imaging investigation has acquired RGB and narrowband 445 to 1013nm multispectral images throughout *Curiosity's* traverse through Gale Crater [4, 5, 6]. These observations have been calibrated to radiance using pre-flight calibration coefficients, and to radiance factor (I/F) using associated observations of the Mastcam calibration target. Initial results from Mastcam multifilter images showed dusty surfaces characteristic of ferric-oxide bearing materials, however, it has been noted previously that some lower albedo surfaces displayed rather flat visible-to-near-infrared spectra. In addition to Mastcam multispectral images, ChemCam passive visible-to-near-infrared spectra (here we focus on the 400-840 nm region) are acquired for each LIBS target. For a full description of this technique see Johnson et al., 2014 [7]. Here we concentrate on ChemCam spectra for several targets elevated in Mn.

Background: Previous visible to near-infrared laboratory studies of Mn oxides show an overall "flattening" across the visible to near-infrared spectral range, with a slight increase in reflectance in the shortest wavelengths and an upturn at longer wavelengths. Mn-replacement of Fe has shown that Mn^{3+} can have an effect on the reflectance spectra of certain minerals. Specifically, relatively weak features due to electronic transitions and crystal field effects are observed in Mn-enriched hematites and goethites at 454, 554, 596 and 700 nm [8]. The Mastcam-34 wide angle camera has filter band-passes at 550, 675 and 750nm, and we will explore the utility of using these bands (or combinations thereof) to determine if there is a contribution of Mn-bearing phases on spectra.

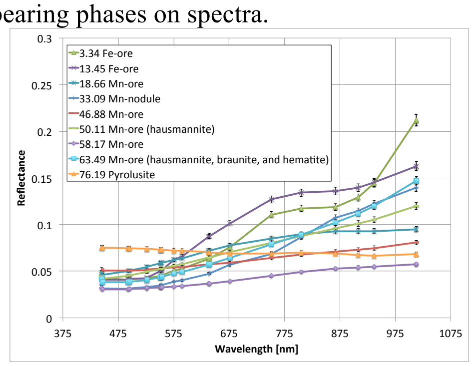

Figure 1: Laboratory visible to near infrared spectra of powdered Mn-oxide standards at p=35 degrees downsampled to Mastcam filter bandpasses. From ~500 – 900 nm the spectrum "flattens" with higher Mn-content. MnO content of samples is provided in the legend.

Methods: We have acquired visible-to-near-infrared reflectance spectra for a suite of Mn-oxide samples using the SCORPIUN laboratory at Arizona State University (ASU) with an ASD Fieldspec 3 Portable Spectroradiometer, attached to a fiber-optic light source and goniometer. The set of standards are micron-sized powders with Mn-oxide abundances that vary from less than 3 up to ~75 wt.%. The ASD spectrometer uses a fixed concave holographic reflective grating that disperses light onto a 512 element photodiode array capable of acquiring data between 350 – 2500 nm with a spectral resolution of 3nm at 700nm and 10nm at 1400/2100nm. The spectrometer is calibrated using a Labsphere Spectralon white reference (SRS-99-10), which is 99% reflective and optically flat (+/- 4%) over the entire spectral range. Sample reflectance is reported relative to the white reference, which is re-acquired after several measurements to correct for any drift in instrument response. The spectra reported here were acquired at a phase angle of 35 degrees and represent the co-adding of over 200 individual ASD measurements for each sample. Laboratory spectra are downsampled to Mastcam bandpasses to determine if the effects of Mn-bearing phases could be identified from Mastcam multispectral observations.

In several locations, both Mastcam full filter and ChemCam passive spectra were acquired for targets found to be elevated in Mn with Chemcam LIBS and APXS. LIBS shots are typically documented with Mastcam-100 color images, however, at typical LIBS distances (~3m) individual shots are not resolvable with the Mastcam-34. On some targets Chemcam LIBS clears surface dust, exposing a relatively dust-free surface that can be readily identified in Mastcam-34 images. This allows for full multifilter spectra to be extracted for many pixels encompassing the entire LIBS raster area. In addition to calibrated spectra from Mastcam multifilter observations of high-Mn targets, we have examined ChemCam passive spectra for the same high Mn-targets identified in [1] and [2]. This work represents the first compilation of ChemCam passive spectra and calibrated Mastcam multispectral images for high-Mn targets. This work also impacts future use of wide-angle Mastcam multispectral images to survey for rock surfaces that might be free of dust and enriched in Mn. Such targets would be suitable for drilling due to their importance to Mars' climate history and their astrobiological potential.

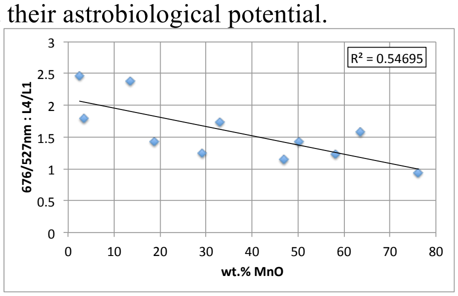

Figure 2: Laboratory-derived 676/527nm band parameter vs. MnO content shows a weak inverse correlation between spectral slope and Mn-content.

Results: Laboratory spectra of Mn-oxide powders are presented in **Fig. 1** (downsampled to Mastcam filter bandpasses). **Fig. 2** demonstrates how increasing Mn-abundance weakly correlates with dereasing spectral slope. In **Fig.3**, we present a subset of the Mastcam and Chemcam spectra for targets elevated in Mn. A wide-angle Mastcam-34 image of the Windjana drill site showing the high-Mn target Stephen is presented in **Fig. 4 (*left*)**. **Fig. 4 (*right*)** shows a band parameter map (867mn/527nm, Mastcam-34 L5/L1) that identifies spectrally flat surfaces (dark in the **Fig.4** right).

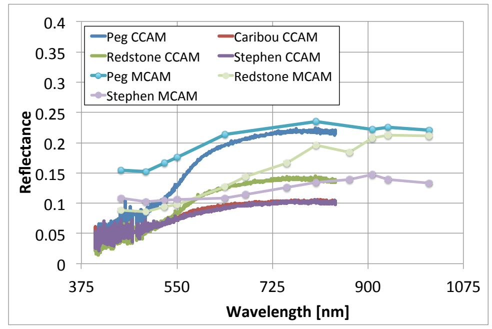

Figure 3: Chemcam passive spectra for Peg, Redstone, Caribou and Stephen with Mastcam full filter spectra for Peg, Redstone and Stephen. These targets were all found to be high in Mn with Chemcam LIBS [1,2]. Note the relatively flat, featureless spectra that are also characteristic of Mn-oxide laboratory spectra.

Summary: Visible-to-near-infrared spectral investigations of Mn-oxide powders and Mn-enriched mineral samples consistently show low albedo (<0.15) and are spectrally flat (from 400 – 900 nm). These spectra are consistent with surfaces that have been identified to have high-Mn in Gale Crater by *Curiosity*. A rudimentary band parameter can be used with the wide field-of-view Mastcam-34, ratioing a low wavelength band to a near-infrared band (867nm / 527nm) and can be used to quickly survey a scene for both less dusty regions as well as surfaces that could potentially harbor Mn-oxide enriched materials.

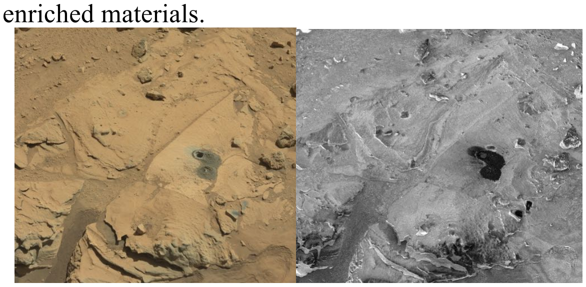

Figure 3: (*left*) A Mastcam-34 L0 image (0626ML0026760010302385E01 NASA/JPL/MSSS) of the Windjana drill site acquired on Sol 626. (*right*) A band parameter image constructed using a ratio of near-infrared to visible Mastcam-34 image bands (L5/L1: L5 = 867 nm; L1 = 527 nm). The ratio image has minimum pixel values when the L5/L1 ratio is lower and the spectrum is more flat from visible to near-infrared wavelengths.

References: [1] Lanza N. et al. (2014) *GRL, 41,* 16, 5755-5763. [2] Lanza N. et al. (*submitted*) *Nature Geosciences*. [3] Arvidson, R.E. et al. (submitted) *Nature Geosciences*. [4] Malin, M.C. et al. (2010) LPSC 41, Abs. #1533 [5] Bell III, J.F. et al. (2012) LPSC 43, Abs. # 2541. [6] Bell III, J.F. et al. (2013) LPSC 44, Abs. #1417. [7] Johnson, J. et al. (2013) LPSC 44, Abs. #1372. [8] Vempati, R.K. et al. (1995) JGR, 100, E2, 3285-3295.